Nitrate concentrations in drainage water in marine clay areas

Exploratory research of the causes of increased nitrate concentrations

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E.M.P.M. van Boekel[1], J. Roelsma[1], H.T.L. Massop[1], R.F.A. Hendriks[1], P.E. Goedhart[2] and P.C. Jansen[1]

1 Alterra, Wageningen UR
2 Biometris

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The nitrate concentrations measured in drainage water and groundwater at LMM farms (farms participating in the National Manure Policy Effects Measurement Network (LLM)) in marine clay areas have decreased with 50% since the mid-nineties. The nitrate concentrations in marine clay areas are on average below 50 mg/L EU target value. A geographical analysis of the monitoring results shows, however, that the nitrate concentrations in 22% of the measurements, mainly taken in the south-western and central marine clay areas, exceed the EU target. The Ministry of Economic Affairs (EZ) commissioned a study to investigate the possible causes of the differences in nitrate concentrations between clay regions. This study shows that the differences in nitrate concentrations are largely due to the specific form of land use combined with the volume of seepage water occurring at LMM farms. This accounts for 43% to 62% of the variation in nitrate concentrations in samples taken from drain pipes at LMM farms from 2006 to 2008. Statistical analysis shows that the average nitrogen surplus of the soil balance of the LMM farms in marine clay areas does not explain the differences in measured (average) nitrate concentrations between these farms. However, the number of farms on clay soils of the LMM-dataset is limited (83 farms in total).

Key words: Nitrate Directive, marine clay areas, drainage water, nitrogen soil surplus, National Manure Policy Effects Measurement Network (LMM)

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Preface

In collaboration with Biometris Wageningen UR, LEI Wageningen UR, RIVM and Deltares, Alterra Wageningen UR was commissioned by the Ministry of Economic Affairs (EZ) to investigate why the nitrate concentrations in the drainage water are higher in the south-western and central marine clay areas than the north-western and north-eastern marine clay areas. In this study the influences of the nitrogen surplus of the soil balance and other land-use and physical-environment factors on the measured nitrate concentration in drainage water was taken into account.

The authors would like to thank all colleagues of Alterra, Deltares, LEI and the RIVM who participated in setting up the research, who contributed to the various sections and helped to complete this report and the study. We would especially like to thank the RIVM for providing the nitrate data from the National Manure Policy Effects Measurement Network (LMM) and the LEI for providing the nitrogen surplus of the soil balances for LMM farms from its database.

A translation agency was commissioned by the Ministry of Economic Affairs (EZ) to translate this report in a very short time. As a result, a limited control was performed on the quality of the translation.

The Authors

Beleidssamenvatting

De gemeten nitraatconcentraties in drain- en grondwater op de LMM-bedrijven in kleigebieden zijn sinds medio jaren 90 gehalveerd. Gemiddeld liggen de nitraatconcentraties in de kleigebieden onder de nitraatnorm van 50 mg/L. Uit de geografische verdeling van de monitoringsresultaten blijkt evenwel dat 22% van de metingen een overschrijding laten zien en dat deze voornamelijk in het Zuidwestelijk en Centraal zeekleigebied liggen. In opdracht van het ministerie van Economische Zaken (EZ) is onderzocht wat de mogelijke oorzaken hiervan zijn.

Gezamenlijk met experts van Alterra Wageningen UR, Deltares en het RIVM is een conceptueel raamwerk opgesteld waarin mogelijke oorzaken op een rij zijn gezet. Hierbij wordt onderscheid gemaakt tussen bedrijfsfactoren (stikstofoverschot, grond-/landgebruik) en mogelijke relevante omgevingsfactoren (bodemtype, hoeveelheid kwelwater, organisch stofgehalte, pyrietgehalte).

Voor het beantwoorden van de beleidsvraag is onderzocht in hoeverre de verhoogde nitraatconcentraties worden veroorzaakt door:

1) *een hoog stikstofbodemoverschot of*
2) *bodem- en grondwatereigenschappen (kleigehalte, kwelwater, organische stofgehalte, pyrietgehalte, etc.) of*
3) *grondgebruikswijze (nadruk op grasland, dan wel nadruk op bouwlandgewassen).*

Op basis van het conceptueel raamwerk is in samenspraak met de experts besloten om in eerste instantie een oriënterende data-analyse uit te voeren waarmee inzicht wordt verkregen in eventuele verschillen in omgevingsfactoren en landgebruik tussen de verschillende zeekleigebieden. Het stikstofbodemoverschot kon op basis van het beperkt aantal bedrijven in bepaalde regio's niet gepresenteerd worden (privacy overwegingen). Wel kon een statistische analyse uitgevoerd worden op de gehele dataset van LMM-bedrijven. Tot slot zijn ook de resultaten van al uitgevoerde modelexercities betrokken in deze studie.

<u>Oriënterende data-analyse</u>
De resultaten van de oriënterende data-analyse zijn in tabel A samengevat.

De verschillen tussen de zeekleigebieden zijn voor de meeste factoren groot. Uit de analyse is echter_ook gebleken dat er een grote variatie is **binnen** de zeekleigebieden. Het blijft hierdoor lastig om op basis van deze oriënterende data-analyse een verklaring te geven voor de hogere gemiddelde nitraatconcentraties in het Zuidwestelijk en Centraal zeekleigebied vergeleken met de overige zeekleigebieden. Om deze reden is nagegaan of met regressieanalyses en met modelonderzoek op bedrijfsniveau met lokale omgevingsfactoren betere onderbouwde conclusies kunnen worden getrokken.

Tabel A
Overzicht van de verschillen tussen de zeekleigebieden voor verschillende parameters.

	Nitraatconcentratie (mg/l)	Dominante eigenschappen						
	Gemiddelde (25-75 percentiel)	Land-gebruik	Pyriet-gehalte	Kwel [2] mm/j	Bodem-type	PAWN-bodem	Gt-klasse	OS-gehalte
Noordoostelijk zeekleigebied	14,9 (3,6 - 21,3)	Grasland (51%)	Gemiddeld	-3,7	Mn [1] (41,5%)	15 (31,0%)	V (46,0%)	Hoog
Noordwestelijk zeekleigebied	24,5 (9,6 - 26,5)	Akkerbouw (76%)	Hoog	-18	Mn [1] (29,3%)	15 (35,6%)	VI (29,7%)	Laag
Centraal zeekleigebied	77,7 (45,5 - 98,0)	Akkerbouw (94%)	Hoog	-172	Mn [1] (61,6%)	16 (26,7%)	VI (46,0%)	Hoog
Zuidwestelijk zeekleigebied	46,9 (25,3 - 60,2	Akkerbouw (89%)	Laag	-33	Mn [1] (70,5%)	15 (36,2%)	VI (63,1%)	Gemiddeld

1) Poldervaaggronden met roest en grijze vlekken beginnend binnen 50 cm
2) Negatieve waarde is netto kwel, positieve waarde is netto wegzijging

<u>Statistische analyse</u>
Van de LMM-bedrijven op zeeklei zijn de bedrijfs- en omgevingsfactoren verzameld en is via een statistische analyse vastgesteld welke variabelen significant van invloed zijn op de gemiddelde nitraatconcentraties van de bedrijven. De nitraatconcentraties en de bedrijfsfactoren (stikstofbodemoverschot, landgebruik) zijn bekend en opgeslagen in de databases van het RIVM en het LEI. De omgevingsfactoren van de LMM-bedrijven zijn bepaald op basis van beschikbaar kaartmateriaal en aan de database van het LEI toegevoegd. Vervolgens zijn multiple regressieanalyses uitgevoerd ('all possible subset selection') waarbij alle variabelen als mogelijke voorspeller van de gemeten nitraatconcentraties worden beschouwd. In tabel B zijn de resultaten weergegeven voor regressiemodellen met resp. 1, 2 of 3 variabelen die in alle jaren (2006, 2007 en 2008) significant zijn. Het toevoegen van meer factoren (variabelen) resulteert niet in een duidelijk betere verklaring van de nitraatconcentratie en bovendien zijn de extra variabelen meestal niet van significante invloed.

Afhankelijk van het meetjaar kan 43% tot 62% van de verschillen in nitraatconcentraties worden toegeschreven aan de verschillen in landgebruik (% grasland en % overig) en verschillen in hoeveelheid kwelwater tussen de LMM-bedrijven. Uit de regressieanalyse blijkt ook dat er een aantal variabelen zijn waarvoor niet voor alle jaren significante relaties worden gevonden en daardoor niet in tabel B zijn opgenomen. Het gaat hierbij om de variabelen *stikstofbodemoverschot*, *organisch stofgehalte in de bodem* en het *pyrietgehalte in de ondergrond* (laag tussen 1,0 en 1,2 meter). Opvallend is dat er geen positieve, maar eerder een negatieve relatie wordt gevonden tussen het stikstofbodemoverschot op de LMM-bedrijven en de gemeten nitraatconcentratie in het drainwater.

Tabel B
Verklarende variantie (%) voor de gemeten nitraatconcentraties in het drainwater voor een aantal regressiemodellen waarbij alle variabelen (= kenmerken van de LMM-bedrijven) voor alle jaren significant zijn.

Jaar	**Percentage verklarende variantie (%)**			
	2006	**2007**	**2008**	**2006-2008**
1 variabele				
% grasland	28	41	47	39
% overig [1]	21	31	37	30
Gt-klasse	25	21	29	26
PAWN-bodem	21	17	21	22
Kwel	8	6	6	8
2 variabelen				
% grasland + Kwel	38	52	57	49
% grasland + % overig	38	48	54	46
% grasland + Gt-klasse	34	46	55	45
% overig + Kwel	32	43	48	42
PAWN + Gt-klasse	41	30	46	41
% overig + Gt-klasse	30	40	49	40
3 variabelen				
% grasland + % overig + Kwel	43	56	62	54

1 akkerbouw, exclusief mais

Uit de regressieanalyse blijkt dat het percentage gras het meest significant is, gevolgd door de hoeveelheid kwelwater (P-waarden uit tabel C; hoe lager de p-waarde des te significanter is de invloed). Het minst significant van deze drie variabelen is het percentage overig landgebruik (akkerbouw exclusief maïs). Een variabele wordt als significant beschouwd als de P-waarde kleiner dan 0,05 is (95% betrouwbaarheid).

Tabel C
Significantie van de variabelen voor het 'beste' model.

Jaar	**P-waarde [1)]**			
	2006	2007	2008	2006-2008
% grasland	0,002	0,000	0,000	0,000
Kwel	0,019	0,001	0,001	0,000
% overig	0,022	0,013	0,006	0,000

1) Hoe kleiner de P-waarde, des te significanter is de parameter

<u>Modelmatige analyse</u>
De verschillen in nitraatconcentraties tussen de kleiregio's kan niet volledig verklaard worden door verschillen in landgebruik en de hoeveelheid kwelwater. Afhankelijk van het weerjaar kan 38% tot 57% van de variatie in nitraatconcentraties niet verklaard worden en liggen er andere oorzaken aan ten grondslag.

Om na te gaan of processen in de bodem (mineralisatie etc.) een rol kunnen spelen bij de verschillen in nitraatconcentraties zijn de resultaten van het proces-georiënteerde nutriëntenuitspoelingsmodel STONE gebruikt, dat in het kader van de evaluatie van de Meststoffenwet 2012 is ingezet voor milieu-analyses.

Hiervoor zijn in eerste instantie uitsluitend de gedraineerde STONE-plots met het bodemtype zeeklei geselecteerd. Vervolgens is verder ingezoomd op STONE-plots die soortgelijke kenmerken bezitten van de beschouwde LMM-bedrijven in de zeekleigebieden.

Uit de analyse blijkt dat het modelsysteem (STONE) goed in staat is om de metingen in het Noordoostelijk, Noordwestelijk en Zuidwestelijk zeekleigebied te beschrijven. Voor het Centraal zeekleigebied worden de nitraatconcentraties echter voor de drie meetseizoenen onderschat. Dit geldt zowel voor het geval waarbij alle zeekleiplots worden beschouwd, maar ook als de geselecteerde plots, met karakteristieken die beter overeenkomen voor de LMM-bedrijven, worden beschouwd.
De onderschatting van de nitraatconcentraties hangt voor een deel samen met een hogere aanvoer van kwelwater waardoor een verdunningseffect optreedt van de berekende nitraatconcentraties. Daarnaast bestaat de indruk dat het voorkomen van krimpscheuren in het Centraal zeekleigebied (vooral de Flevopolders) er preferent transport op kan treden door scheurvorming. Het gaat dan vooral om rijpingsscheuren die zijn ontstaan tijdens de drooglegging van deze polders. In het huidige modelinstrumentarium STONE zijn deze routes nog niet opgenomen, waardoor de berekende nitraatconcentraties hoogstwaarschijnlijk lager zijn dan de gemeten concentraties. Omdat de berekende nitraatconcentraties niet voor alle zeekleigebieden overeenkomen met de gemeten nitraatconcentraties, is geconcludeerd dat eerst in alle gebieden de berekeningen goed moeten gaan voordat op basis van STONE-berekeningen specifieke aanvullende conclusies mogen en kunnen worden getrokken over factoren die de nitraatconcentratie in zeekleigebieden beïnvloeden.

Samenvattend kan worden geconcludeerd dat de (plaatselijk) hogere nitraatconcentraties in het Zuidwestelijk en Centraal zeekleigebied voor een aanzienlijk deel verklaard kunnen worden uit het landgebruik (aandeel gras en aandeel akker- en tuinbouw excl. maïs) en de hoeveelheid kwelwater op de betrokken bedrijven. Het stikstofoverschot lijkt op basis van de data uit de LEI- en LMM-database geen verklaring te geven voor hogere nitraatconcentratie in het Zuidwestelijk en Centraal zeekleigebied.
Mogelijkerwijs kan door inbrengen van het optreden van krimpscheuren in het modelinstrumentarium STONE uiteindelijk voor alle zeekleigebieden een goede fit gevonden worden tussen gemeten en berekende nitraatconcentraties, waardoor uiteindelijk ook nog het niet-verklaarde deel in de statistische analyse verklaard kan worden.

Als er behoefte is dat ook bij bedrijven in zeekleigebieden er geen overschrijdingen meer plaatsvinden van de nitraatconcentratie in het grondwater en drainwater, wordt aanbevolen om de LMM-bedrijven specifiek modelmatig door te rekenen (nadat het effect van krimpscheuren is ingebracht) en een validatie uit te voeren. Op basis van betrouwbare uitkomsten kan via scenariostudies vastgesteld worden wat de effectiviteit is van verschillende maatregelen. Hierbij kan gedacht worden aan bemestingsstrategieën, eventueel in combinatie met ander landgebruik, hydrologische ingrepen (wel of geen buisdrainage, meer of mindere mate van kwel, beperkt vasthouden van water om de denitrificatiecapaciteit te verhogen).

Executive summary

The nitrate concentrations in groundwater and/or water of pipe drains on the farms of the LMM monitoring network have decreased with 50% since the mid-nineties. In the marine clay region the average nitrate concentration is below the 50 mg NO_3/l EU target value. A geographical analysis of measured nitrate concentrations shows that 22% of the observed clay soils exceed the EU target value. Most of these high nitrate concentrations are observed in south-western and central marine clay area.

A study was conducted to investigate to what extent the higher nitrate concentrations in the south-western and central marine clay area can be explained by:

1) *a high average nitrogen surplus of the soil balance of the LMM farms or*
2) *soil and groundwater characteristics (clay content, seepage water, organic matter content, pyrite content etc.) or*
3) *land use (emphasis on grassland or emphasis on arable land).*

As a first step, a conceptual analytical framework was set up by experts from different institutes (Alterra Wageningen UR, Deltares and RIVM), in order to evaluate the effects of soil processes on nitrate concentrations, especially in clay soils. The influence of regional characteristics and land use between the different marine clay areas were also analysed (north-western, north-eastern, central en south-western marine clay area). Secondly, a statistical analysis was carried out on the dataset of the LMM farms. Finally, results from model calculations that have been carried out, as part of the evaluation of Manure Act (2012), were also taken into account.

<u>Process oriented data-analysis</u>
In Table A the average nitrate concentration and information of relevant characteristics (as discussed in Chapter 3.2) are presented for each clay region.

The average nitrate concentration between the marine clay areas range from 14.9 to 77.7 mg nitrate per litre. The analysis showed that the differences between the regional characteristics are large, however the variation of the regional characteristics within a marine clay areas were also large. Due to these high variations in characteristics within the regions it was not possible to explain directly the higher average nitrate concentrations in the south-western and central marine clay area based on this regional information. Therefore, additional regression-analysis and model exercises were performed *on farm level with local* parameters.

Table A

Overview of nitrate concentrations and relevant characteristics of the regions.

	Observed nitrate concentration (mg/l)	Information of relevant characteristics of the agricultural area in the regions						
	Average (25-75 percentile)	Dominant land use	Pyrite-content	Seepage [1] mm/j	Dominant soil-type		Hydrology	OM-content
North-eastern marine clay area	14.9 (3.6 - 21.3)	Grassland (51%) [2]	Medium	-3.7	Mn [3] (41.5%	15 [4] (31.0%)	Moderate dry soils (46.0%)	High
North-western marine clay area	24.5 (9.6 - 26.5)	Arable land (76%) [2]	High	-18	Mn [3] (29.3%)	15 [4] (35.6%)	Dry soils (29.7%)	Low
central marine clay area	77.7 (45.5 - 98.0)	Arable land (94%) [2]	High	-172	Mn [3] (61.6%)	16 [5] (26.7%)	Dry soils (46.0%)	High
South-western marine clay area	46.9 (25.3 - 60.2	Arable land (89%) [2]	Low	-33	Mn [3] (70.5%)	15 [4] (36.2%)	Dry soils (63.1%)	Medium

1) Negative value is upwards seepage, positive value is downwards seepages
2) Percentage of the total agricultural area
3) Marine clay soils with rust and grey spots within 50 cm
4) Homogeneous silt soils
5) Homogeneous light clay soils

<u>Statistical analysis</u>

The characteristics of the LMM farms were derived from the LMM databases or from maps. Multiple linear regression analyses were used to determine which characteristics significantly influence the average nitrate concentrations of farms. All characteristics were considered as possible variables which may predict measured nitrate concentrations. The results of regression models with significant variables (up to 3) for the years 2006, 2007 and 2008 are presented in Table B. Regression models with more than three variables do not results in a significant better explanation of the measured nitrate concentration. Only the variables that had a significant effect were included in Table B. Some variables were not significant for all years or were not significant at all (e.g. nitrogen surplus of the soil system, organic matter content and pyrite content).

Depending on the year in which measurements were conducted about 43% to 62% of differences in measured nitrate concentrations between the LMM farms can be attributed to differences in land use (% grassland and % arable land (exclusive maize) and differences in the amount of upward seepage between the LMM farms. The most significant characteristic is the percentage of grassland, followed by the amount of upward seepage and the percentage of arable land (exclusive maize land).

Based on the results of the regression analysis, it seems that there is a negative relation between the percentage of grassland and the amount of upward seepage and a positive relation between the percentages of arable land. *This means that the higher the percentage of grassland and the amount of upward seepage, the lower the nitrogen concentrations (regression coefficients not shown). In case the upward seepage increases, there is more dilution of the nitrate concentration which results into a lower nitrate concentration.*

Remarkably, there was also a negative relation found between the nitrogen surplus of the soil balance and the nitrate concentration in drain water (Table 15 in this report) if only this factor was taken into account.

Table B

Percentage explained variance of the measured nitrate concentration in groundwater or drainage water for regression models in which all variables (= characteristics of the LMM farms) are significant for all years.

Year	Percentage explained variance (%)			
	2006	**2007**	**2008**	**2006-2008**
1 Variable				
% grassland	28	41	47	39
% arable land [1]	21	31	37	30
Groundwater table	25	21	29	26
Soil type	21	17	21	22
Upward seepage	8	6	6	8
2 Variables				
% grassland + Upward seepage	38	52	57	49
% grassland + % rest	38	48	54	46
% grassland + Groundwater table	34	46	55	45
% arable land + Upward seepage	32	43	48	42
Soil type + Groundwater table	41	30	46	41
% arable land + Groundwater table	30	40	49	40
3 Variables				
% grassland + % arable land + Upward seepage	43	56	62	54

1 Arable land, exclusive maize

Model application

The differences in nitrate concentrations between clay areas could only partly be explained by differences in land use and the amount of upward seepage. However, 38% to 57% of the variation in nitrate concentrations could not be explained by the variation of these parameters. Obviously, other parameters also influence the variation of the nitrate concentration.

To investigate if soil processes (e.g. mineralisation) may explain a part of the variation of nitrate concentrations, the results of the process-oriented nutrient emission model STONE was used. STONE was designed for evaluation at the national and regional scale of the effects of changes in the agricultural sector (e.g. changes in fertilizer recommendations and cropping patterns) and in policy measures (e.g. EU nitrate directive for ground water) for the leaching of nitrogen (N) and phosphorus (P) from agricultural land areas to ground water and surface waters.

The STONE model simulated well the measured nitrate concentrations in the north-eastern, north-western en south-western marine clay areas. The measured nitrate concentrations in the central clay area however have been underestimated for all years, which may be explained by the high amount of seepage water in the (available) model application (dilution effect) and additional preferential water flows in cracked soils which may have resulted in higher nitrate concentrations in practice. Cracked soils are not yet implemented in the STONE-model, but can have a significant effect on nutrient leaching.

Conclusions

Based on this study the nitrogen surplus of the soil system of the LMM farms, derived from the LEI- and RIVM-database, does not provide an explanation for the higher nitrate concentrations in the south-western and central marine clay. In all clay regions no positive relationships were found between the average nitrogen surplus of the soil balance of the LMM farms and the measured average nitrate concentration of the LMM farms.

The local higher nitrate concentrations at the LMM farms in the south-western and central marine clay area can partly be explained by the land use (percentage grassland and arable land, exclusive maize) and the amount of upward seepage water. The higher the percentage of grassland and the amount of upward seepage, the lower the nitrate concentration.

The STONE-model application can help to get a better understanding of the measured nitrate concentrations because much more processes are taken into account which cannot be used (on forehand) in statistical analysis (mineralisation, denitrification etc.). However it is recommended to incorporate the influence of preferential flow in cracked soils into the model before such evaluations are made, because cracked soils occur in the central clay area and can cause additional losses of nutrients. Subsequently scenario analysis can be performed to determine the effectiveness of mitigation options. Possible mitigation options are for example fertilisation strategies in combination with a certain type of land use and hydrological measures (e.g. control drain pipes, holding water to increase the denitrification capacity).

1 Introduction

1.1 Background

The Nitrate Directive (Directive 91/676/EEC) is an European legislation that has the dual objective of reducing water pollution caused by nitrate from agricultural sources and preventing further contamination. In this respect, the EU has adopted a limiting value of 50 mg nitrate/L in groundwater and surface water. The directive orders member states to set up an action programme for areas vulnerable to nitrate leaching that must be reviewed and, if necessary, revised at least once every four years. When the directive came into effect, the Netherlands designated all agricultural land as vulnerable to nitrate leaching.
The fourth action programme for the 2010-2013 period (Ministry of Agriculture, 2009) included measures designed to achieve the target values specified in the Nitrate Directive. The application standards for specific forms of land use are a crucial element of the measures. From 1992 to 2010, the average nitrate concentration in the top layer of groundwater in sand regions decreased by approximately 50% (Hooijboer en De Klijne; Van der bolt et al.; EMW, 2012). In general, the quality of the groundwater in peat areas meets with the requirements of the nitrate norm and, on average; this also applies to clay areas.

The clay areas as a whole therefore meet the targets specified in the Nitrate Directive. However, the nitrate concentrations in 22% of the measured locations points exceed the EU-target (Hooijboer and De Klijne, 2012). The geographical spread of the monitoring results for nitrate (in the 2007-2010 period) shows that these relative high nitrate concentrations are mainly located in the south-western marine clay area (Zeeland) and the central marine clay area (Flevoland) (figure 1, Hooijboer and Klijne, 2012).

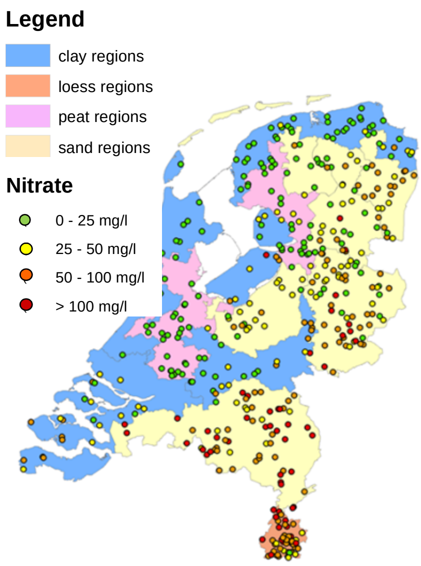


Figure 1
Categorisation of LMM farms in classes based on the average nitrate concentration in leaching water, 2007-2010 (Hooijboer and Klijne, 2012).

1.2 Objective

Alterra was commissioned by the Ministry of Economic Affairs (EZ) to investigate the possible causes of the higher nitrate concentrations observed in the south-western and central marine clay areas.

In order to answer the research questions, the influence of the following factors was studied:
1) *a high average nitrogen surplus of the soil balance of the LMM farms or*
2) *soil and groundwater characteristics (clay content, seepage water, organic matter content, pyrite content etc.) or*
3) *land use (emphasis on grassland or emphasis on arable land).*

1.3 How to interpret the report

- Section 2 discussed the different phases of the study and describes the methods used in each phase.
- The results of the different phases are presented sequentially in Section 3 (preliminary phase), Section 4 (phase 1) and Section 5 (Phase 2). At the end of each section, the results are discussed and recommendations are made.
- Section 6 contains the conclusions in respect of the research questions and recommendations for future policy.
- An executive summary of the research is given above.

2 Method

The study was carried out from 2010 to 2012 and was divided into a number of phases that were subsequently subdivided into different activities (table 1). The content of the different phases and the underlying elements was regularly modified and revised during the course of the study. In this section, the different phases and activities are further explained.

Table 1
Overview of the phases and related activities carried out during the study.

Phase	Activities	Description
Preliminary phase	A: Exploratory data analysis	Exploratory data analysis of the nitrate concentrations measured at LMM farms in marine clay areas
	B: The set-up of a conceptual framework	Systematic exploration of sources and processes that affect nitrate concentrations in groundwater and drainage water
	C: Discussion meeting	Discussion of the results of the preliminary phase and the details for phase 1 with experts from Alterra, Deltares and RIVM
Phase 1	A: Exploratory data analysis	Exploratory data analysis of relevant, regional characteristics of the marine clay areas
	B: Farm analysis: nitrogen surplus of the soil balance	Analysis of the nitrogen surplus of the soil balance in relation to the nitrate concentrations measured at LMM farms
Phase 2	A: Statistical analysis	The collection of regional characteristics of LMM farms and the performance of statistical analysis
	B: Model-based analysis	Analysis of the calculated nitrate leaching per region using the STONE model

2.1 Preliminary phase

The preliminary phase of the project consisted of two components:
- Exploratory data analysis of the nitrate concentrations measured at farms that participate in the National Manure Policy Effects Measurement Network (LMM) and that are situated in marine clay areas in the Netherlands (north-western, north-eastern, central and south-western marine clay areas).
- The set-up of a conceptual framework for discussing all the factors that could (possibly) affect the nitrate concentrations in drainage water and groundwater in marine clay areas.

Exploratory data analysis
The data from the LMM farms in the south-western and central marine clay areas precipitated an additional study to look into the (possible) causes of the higher nitrate concentration in these particular areas. Before investigating the possible causes, an exploratory data analysis was performed of the nitrate concentrations measured at the LMM farms in the 1996-2008 period.

For the purposes of the study, the entire marine clay region of the Netherlands was divided into the following four areas:
- The south-western marine clay area (Zeeland).
- The central marine clay area (Flevoland).
- The north-western marine clay area (Noord-Holland).
- The north-eastern marine clay area (Groningen/Friesland).

Conceptual framework
The relatively high nitrate concentrations in the groundwater and/or drainage water of pipe drains in the south-western and central marine clay areas, compared with the other marine clay areas, can possibly be explained by differences in regional characteristics.
The conceptual framework outlines a system for exploring processes that may play a role in controlling the nitrate concentration in the groundwater and drainage water of marine clay soils.

Discussion meeting
After the analysis of the LMM measurement data and the drafting of the conceptual framework were completed, a discussion meeting was organised for experts from Alterra, Deltares and the RIVM. The purposes of the meeting were to:
- Derive consensus regarding the conceptual framework.
- Identify relevant nitrogen sources.
- Identify processes and important local factors.
- Finalise plans for phase 1.

2.2 Phase 1

Phase 1 consisted of two components:
- Exploratory data analysis of the differences in relevant, regional characteristics of the separate marine clay areas.
- Analysis of the nitrogen surplus of the soil balance in relation to the nitrate concentrations measured at the LMM farms in the marine clay areas.

Inventory and analysis of (regional) factors
During the meeting between experts from Alterra, the RIVM and Deltares, a number of relevant, regional factors were put forward that could not be excluded in advance as possible explanations for the nitrate concentrations measured in the drainage water/groundwater at the LMM farms. Further investigation of all the factors, working from global to fine data was recommended. Phase 1 started with an exploratory data analysis to obtain insight into whether any differences were visible in relevant, regional characteristics of the separate marine clay areas.

Statistical analysis of the nitrogen surplus of the soil balance and nitrate concentrations
An additional component of phase 1was to investigate whether there was an significant relationship between the nitrogen surplus of the soil balances and the nitrate concentrations measured on a farm level. A statistical regression analysis was performed using the nitrogen surplus of the soil balance (on a farm level), established by the LEI for the LMM–network (source: LEI data) and the (average farm) nitrate concentrations in the RIVM database (source: RIVM/LMM). The results of the statistical analysis were important for working out the details for phase 2 of the study.

Decision moment If phase 1 showed that the nitrogen surplus of the soil balance did *not* adequately explain the nitrate concentrations measured at the LMM farms, phase 2 would be initiated.

2.3 Phase 2

Phase 2 focused on the direct relationship between the characteristics of the LMM farms and the nitrate concentrations measured in drainage water of those farms. Phase 2 consisted of two components:
- Data collection and statistical analysis on a farm level.
- Model-based analysis.

Data collection and statistical analysis
In order to make the statistical analysis of the relationships between nitrate concentrations and the characteristics of the LMM farms reliable, it had to be based on raw data, i.e. the measurements taken on a farm level. The problem with the LMM data was that the local characteristics were not all measured. It was recommended that the necessary data on relevant characteristics should be collected locally (i.e. on the LMM plots) in combination with nitrate concentration measurements (taken from the same respective plots). However, in view of the available time for completing the project and the related costs, setting up this type of measuring plan was not feasible and consequently a different approach had to be chosen.

The characteristics of the LMM farms were defined on the basis of various data files and maps and subsequently stored in a database for use in a statistical regression analysis. The analysis looked into the relationship between nitrate concentration on the one hand and the groundwater table classes, soil type, volume of seepage water, organic matter content and pyrite content on the other hand from 2006 to 2008. Besides the aforementioned characteristics, the land use was also included as an explanatory variable. The aim of the analysis was to obtain insight into whether there was a significant relationship between the measured nitrate concentrations and the characteristics of the farms.

Model-based analysis
The relevant routes and processes could not all be identified solely on (field) measurements (for example, mineralisation). Some relevant variables could either not be measured at the correct location or at the correct moment in time. Phase 2 of the project required the application of the STONE-model (Wolf et al., 2003) in order to be able to interpret the measurements.

The model-based analysis was performed in two steps. In step 1, the model results (nitrate concentration in drainage water) for the individual clay regions were tested against the measurements taken at the LMM farms. In step 2, the unique combinations (land use, soil type and hydrology) of the LMM farms in the regions were linked to characteristic STONE calculation units. Subsequently, the results of these selected calculation units were again tested against the LMM farm measurements and analysed for differences between the regions.

3 Results preliminary phase

The results of the exploratory data analysis are given in paragraph 3.1; the conceptual framework is outlined in paragraph 3.2. The arguments and recommendations for the subsequent phase are presented in paragraph 3.3.

3.1 Exploratory data analysis

In the preliminary phase of the study, an exploratory analysis was performed of the nitrate figures from 1996 to 2008 measured at LMM farms in the different marine clay areas in the Netherlands:
- South-western marine clay area (Zeeland and parts of Zuid-Holland and Noord-Brabant).
- Central marine clay area (Flevoland).
- North-western marine clay area (Noord-Holland).
- North-eastern marine clay area (Friesland, Groningen).

For the purpose of performing the exploratory data analysis, the north-western and north-eastern marine clay areas were combined (to form the northern marine clay area).

<u>Selection of LMM farms</u>
For the exploratory data analysis, all farms in the clay regions were selected if the water sampling took place in the six-month winter period. This meant that farms located in the fluvial clay region (outside the investigated areas) were selected as well. An overview of the number of farms in the clay region and the fraction of the farmland area with marine clay soil is given in Table 2.

Table 2
Number of farms in clay areas and the related fraction of farmland with marine clay soil.

Marine clay fraction	Number of farms	
	Total	Selection
< 10%	50	-
10-50%	7	7
50-60%	2	2
60-70%	6	6
70-80%	6	6
80-90%	12	12
> 90%	127	127
Unknown	2	-
Total	**212**	**160**

A total of 212 farms were selected in the clay areas (including fluvial clay). For the exploratory analysis, only farms were selected with an area consisting of more than 10% marine clay (160 farms).

In Figure 2, the locations of the farms in the clay regions are shown before the selection (left) and after the selection (right). This shows that selection on the basis of the fraction of marine clay is an effective method. As a result of the selection, farms especially in the fluvial clay area were filtered out of the database.

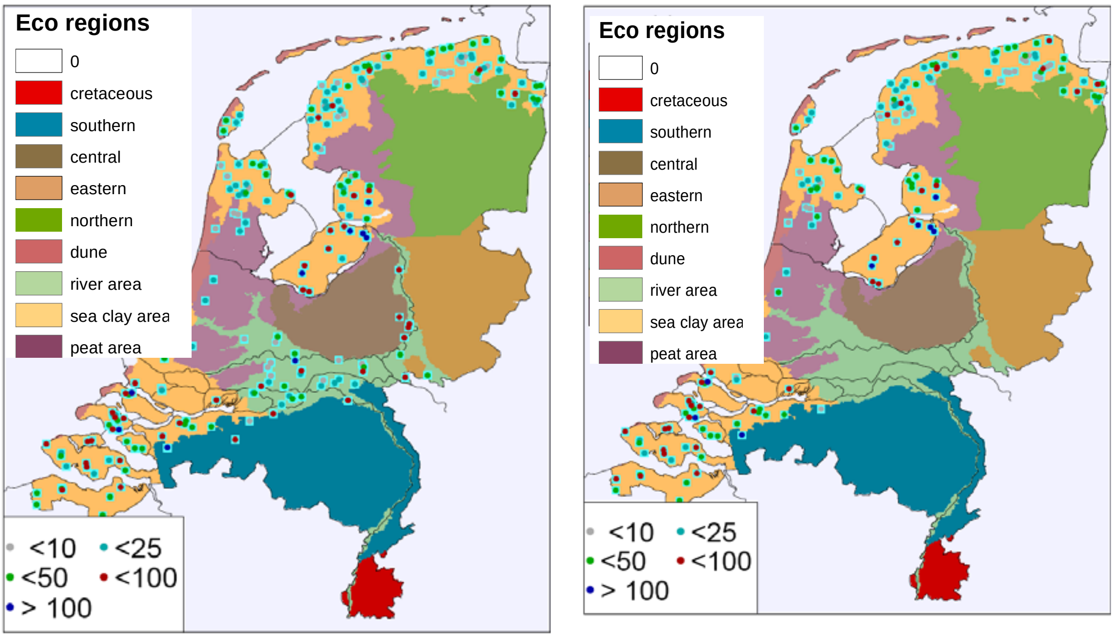


Figure 2

LMM farms that participated in the clay programmes from 1996 to 2008.

LMM farms with at least 10% marine clay in their acreage and that participated in the clay programmes from 1996 to 2008.

Either the drainage water of pipe drains or the groundwater of each farm was sampled. In some situations, in one year the groundwater was sampled and in another year the drainage water. Groundwater sampling took place at farms if less than 25% of the drain pipes were active. Groundwater sampling was only started in 2002 and involves (much) fewer farms than drainage water sampling (Figure 3).

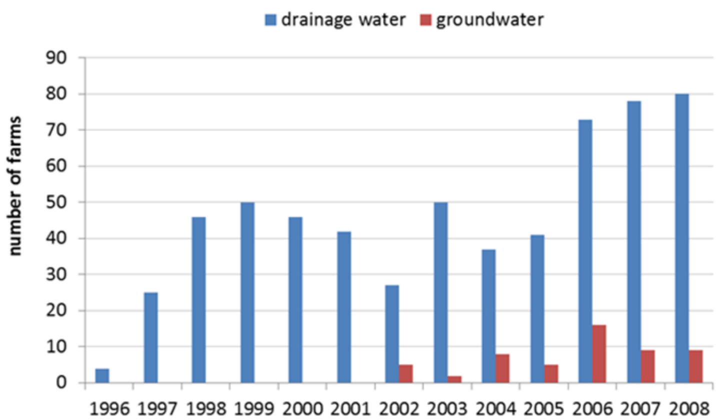


Figure 3

Number of farms of which the drainage water or groundwater was sampled from 1996 to 2008.

The number of farms is larger in the northern marine clay area than in the other clay areas; the number of farms selected in the central marine clay area was the lowest (Figure 4).

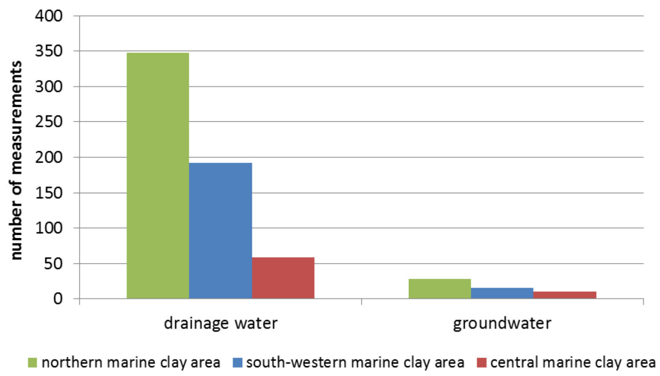


Figure 4
Total number of drainage water and groundwater nitrate measurements carried out in the northern, south-western and central marine clay areas from 1996 to 2008.

Nitrate concentrations
The trends in average nitrate concentrations from 1996 to 2008 were analysed for the different marine clay areas. In this respect, a distinction was made between nitrate concentrations in drainage water and in groundwater (Figures 5 to 7). The figures above the 'markers' show the number of farms. The nitrate concentrations have **not** been corrected for weather conditions.

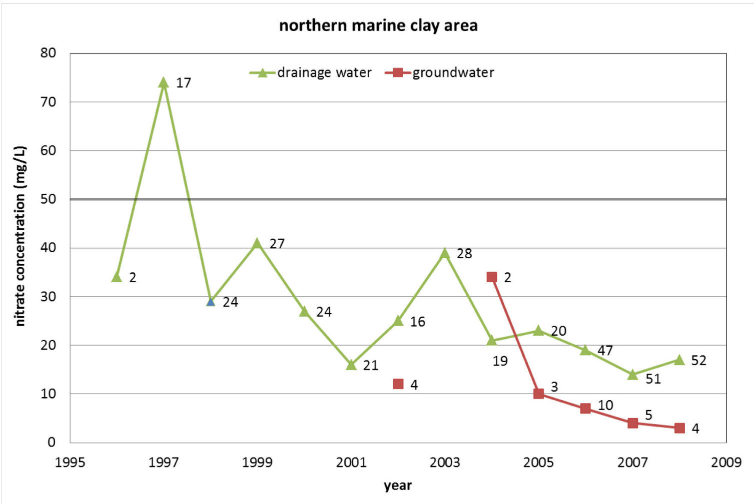


Figure 5
Average nitrate concentration (mg/L NO_3^-) for farms in the northern marine clay area (Groningen, Friesland and Noord-Holland) for 1996 to 2008 in drainage water and groundwater, including the number of samples.

The average nitrate concentrations in the drainage water at LMM farms in the northern marine clay area show a declining trend from 1996 and, with the exception of 1997, are below the 50 mg/L EU target. The nitrate concentrations in groundwater are generally lower than in drainage water (with the exception of 2004).

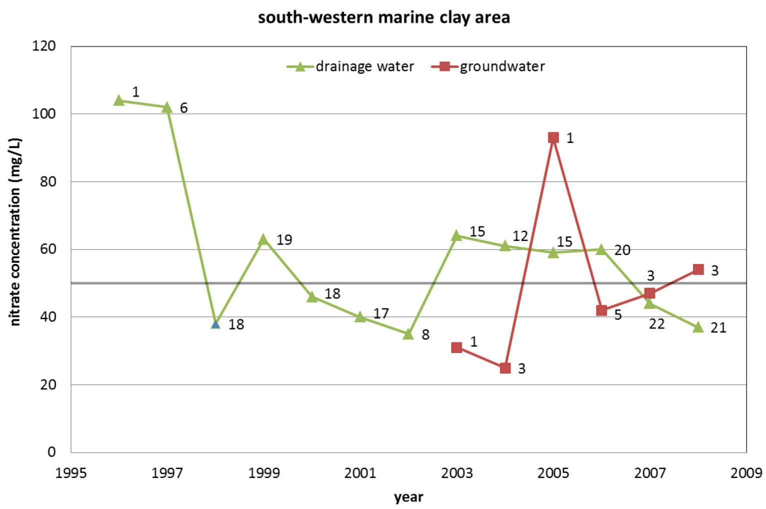


Figure 6
Average nitrate concentration (mg/L NO_3^-) for the south-western marine clay area (Zeeland) from 1996 to 2008 in drainage water and in groundwater, including the number of samples.

The nitrate concentrations in the drainage water at LMM farms in the south-western marine clay area vary globally from 30 to 70 mg/L from 1998 to 2008. In 1996 and 1997, the average nitrate concentrations were well in excess of 100 mg/ L. However, the number of participating farms in these two years was limited to one and six, respectively. The nitrate concentrations in groundwater increased from 2003 and were in 2008 and 2009 higher than the nitrate concentrations measured in drainage water. With respect to this table, it should also be remarked that the number of participating farms of which the groundwater was sampled was limited and the figures have not been corrected for weather conditions.

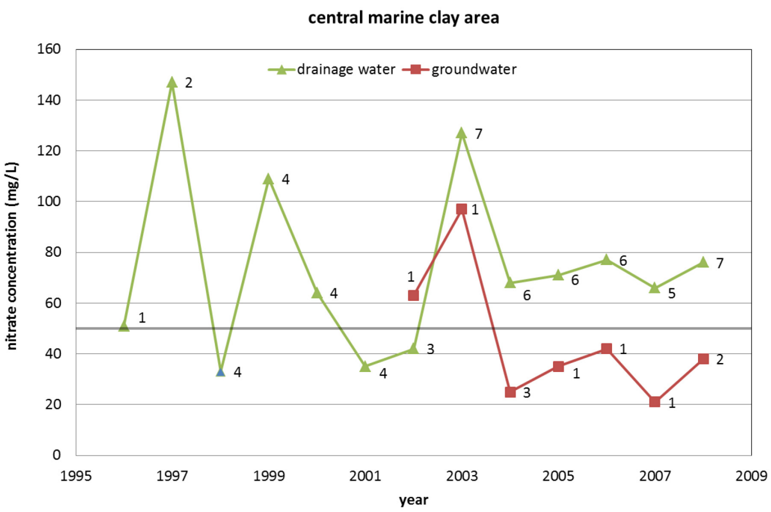
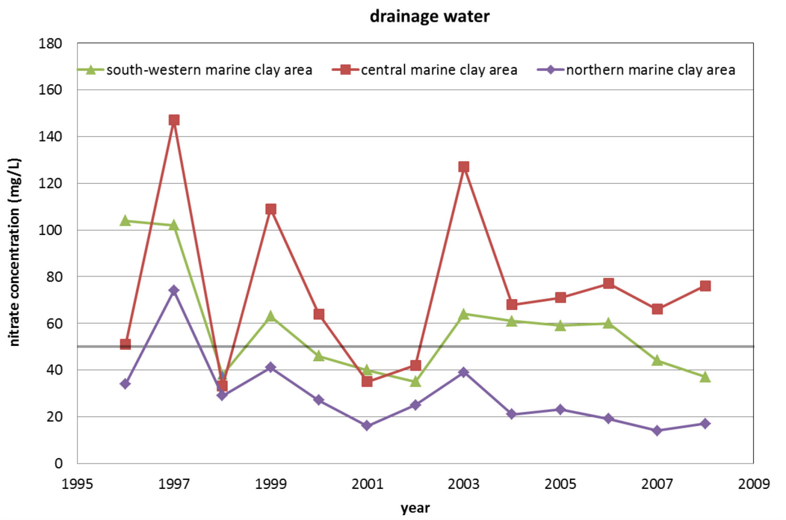


Figure 7
Average nitrate concentration (mg/L NO_3^-) for the central marine clay area (Flevoland) from 1996 to 2008 in drainage water and in groundwater, including the number of samples.

The nitrate concentrations in the drainage water at LMM farms in the central marine clay area varied from 1996 to 2004 from 30 to 150 mg/L. After 2004, the variation was smaller (65-80 mg/L).
The nitrate concentrations in groundwater are generally lower than in drainage water (with the exception of 2002). With respect to this table, it should also be remarked that the number of participating farms was limited and the nitrate figures have not been corrected for weather conditions.

The average nitrate concentrations in the drainage water and groundwater in the different marine clay areas were subsequently compared (Figure 8).



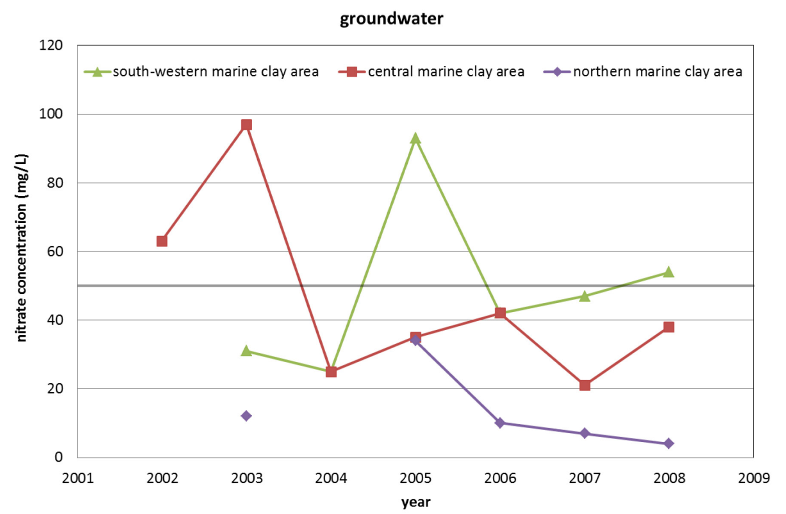


Figure 8
Average nitrate concentration (mg/L NO_3) in the drainage water from 1996 to 2008 (top figure) and in the groundwater (bottom figure) from 2002 to 2008.

The average nitrate concentrations in the drainage water and in the groundwater were lower in the northern marine clay area than in the central and south-western marine clay areas. The highest nitrate concentrations in drainage water were measured in the central marine clay area; the highest nitrate concentrations in groundwater were found in the south-western marine clay area.

3.2 Conceptual framework

The results of the exploratory data analysis indicated a need for additional analysis to establish the causes of the differences in nitrate concentrations in drainage water/groundwater between the marine clay areas. In order to be able to answer this question, it was necessary to analyse the sources and processes that (could) affect the nitrate concentrations in drainage water/groundwater.
These sources and processes are described in the following paragraph.

Sources + processes

(Nitrogen) sources and the formation of nitrate
The most important sources of nitrogen on agricultural land is the application of manure and chemical fertilisers. A study carried out in 2008 (Van Boekel et al., 2008) showed that approximately 15-19% of the nitrogen surplus of the soil balances leaches into the groundwater and surface water.

Another source of nitrogen is seepage. Nitrogen in the form of ammonium can be carried in seepage water flowing along deep streamlines. Seepage usually discharges directly or via drains into the surface water. Because conditions along this route are not usually aerobic, any nitrification will be negligible; therefore seepage cannot be expected to constitute a significant source of nitrate. Other sources of nitrogen are atmospheric deposition and infiltration water (from surface water).

Secondary supply of nitrogen from the soil
Besides nitrogen from fertilisers, seepage, deposition and infiltration water, the degradation of organic matter (mineralisation) is also a source. Mineralisation is the term used to refer to the process in which organic compounds in or on the surface of the soil are broken down by micro-organisms to form inorganic (mineral) compounds. The conversion of organic nitrogen into nitrate takes place in two steps. At first organic nitrogen is converted into ammonium (NH_4^+) and is referred to as N-mineralisation. Under aerobic conditions, the ammonium is subsequently converted into nitrate (via nitrite (NO_2^-)). The process in which ammonium is converted into nitrate is referred as nitrification.

(Nitrogen) removal and nitrate reduction
Nitrogen can disappear from the soil system in various ways: uptake by crops and harvest, conversion into other substances (nitrate reduction) and 'physical' removal (discharge to groundwater and surface water).

The chemical reduction of nitrate (denitrification) is a biogeochemical process that takes place under anaerobic conditions and involves different types of soil bacteria. These bacteria can obtain energy by oxidising organic matter (peat, manure) or inorganic matter, such as pyrite (FeS_2).
The potential of the soil to break down nitrate via denitrification therefore also depends on the occurrence of organic matter and/or pyrite. Whether this potential can be fully utilised depends in turn on the hydrological processes that regulate the transport of substances through the soil. Slow percolation makes denitrification more likely than fast discharge through preferential streamlines.

The 'physical' removal of nitrogen (including nitrate) under agricultural land partly depends on hydrological conditions (water content, groundwater fluctuation and position and length of water flow streamlines to groundwater and surface water) and the position of the nitrate concentration in the soil profile. Hydrological processes and the occurrence of nitrate are strongly influenced by the physical soil condition, soil profile structure and the drainage components in use.

Factors
The following section provides an overview of the ***most important*** factors that can affect nitrate concentrations in drainage water/groundwater. The list of factors is incomplete because other sources, factors and processes may play a role locally or regionally.
The factors have been globally divided into two groups: farm-specific and physical-environmental.

Farm-specific factors
The farm-specific factors that can affect the nitrate concentrations in drainage water/groundwater are mainly related to type of agriculture:
- Fertilisation intensity (nitrogen surplus) and prevailing nutrient levels in cultivated land.
- Land use (arable farming versus grassland).
- Extent and time of grazing (autumn grazing).
- The occurrence and characteristics of drainage systems (drain pipes).

Fertilisation intensity and nutrient levels
The amount of fertilisers that remains in the soil at the end of the growing season (nitrogen surplus) largely determines the risk of leaching to groundwater and drainage into surface water. Especially in the past, part of the fertiliser application on clay soils was spread in the autumn. Some of the nitrogen in fertilisers that cannot be taken up by plants accumulates in the soil (increase in the nitrogen in organic matter or as mineral nitrogen; Nmin). During the winter, the processes outlined above are responsible for converting soil nitrogen into nitrate that subsequently leaches into the groundwater and/or surface water.

If the soil hydrology is dominated by preferential streamlines, for example, macrospores in heavy clay soils, the nitrification process may not have a chance of occurring and nitrogen will exit the soil system in the form of organic N and/or ammonium and flow into the groundwater and surface water. It should be remarked that, because of this, the denitrification process will also not have a chance of occurring and any nitrate already in the system will leach out. In addition, the nitrification capacity strongly depends on precipitation levels, the groundwater level and soil temperature, which means there can be significant differences between years.

Land use
The fraction of the nitrogen surplus in the soil balance that leaches into the groundwater and surface water (leaching factor) varies depending on soil use and soil type (Fraters et al., 2007). This study showed that the leaching factor for clay soil used for arable farming was 3 times higher than for clay soil used for grassland.

The occurrence and characteristics of drainage systems
The groundwater level for drained land is generally low, which can consequently impact negatively on the water quality because the denitrification capacity is lower with lower groundwater levels than with higher groundwater levels.

The depth and distance between drainage components co-determines the streamlines (discharge to groundwater or surface water) and the retention times of the precipitation surplus. With shorter travelling times and distances to a drain, less reduction (for example denitrification) and buffering takes place en route. The depth and distance between drain pipes partly depends on soil type. In sandy soils, but also in, for example, fractured clay soils in Flevoland, the distance between drain pipes is larger than in the other clay areas (C.R. Meinardi, RIVM, 1997).

Physical-environment factors
Besides farm-specific factors, physical-environment factors also influence nitrate concentrations in drainage water/groundwater.

Precipitation surplus
The nitrate concentration in drainage water (mg/L) is primarily determined by the quantities of nitrate NO3 (mg) and water (L) that are present. If the absolute quantity of nitrate remains the same and other processes are not active, dry conditions will consequently lead to higher concentrations and wet conditions to lower concentrations (dilution effect). In order to compare nitrate concentrations between marine clay areas and different years properly, a correction has to be made for the precipitation surplus.

Physical soil characteristics
The 'transport' of water and dissolved nutrients through the soil is determined by the physical characteristics of the soil. These can be described by the water retention (pF curve) and the permeability characteristics. The pF curve plots the relationship between moisture content and moisture tension in unsaturated soils. The permeability characteristic plots the relationship between unsaturated permeability and moisture tension. These characteristics are mainly determined by the texture of the soil, the organic matter content and the density.

An extreme aspect of this is the formation of ripening and/or shrinkage cracks extending from surface level to the depth of drain pipes (Van den Akker et al., 2010 and 2011), or if no drain pipes are present, branching out as a three-dimensional network leading to ditches.

The formation of these cracks enables water and dissolved minerals to seek out preferential streamlines that vastly accelerate discharge into drainage components. Lutum content, the composition of the clay minerals, organic matter and calcium content, interfering layers and the drainage depth influence this (Van den Akker et al., 2010). If the top 30-50 cm of farmland soil is disturbed by ploughing, cracks will not start at surface level, but in the subsoil under the ploughed layer. In this type of situation, cracks will have an even greater accelerating effect on the water discharge into drainage components. This means that cracks at a depth of 30-50 cm can act as a type of drain for the topsoil (Groen, 1997). As a result, the distances between drain pipes in soils with shrinkage cracks can be much greater than in soils without cracks. For example, 48 m in soil with ripening cracks (Groen, 1997), compared with 8-18 m in soil without large ripening cracks (Vos et al., 2005). A more detailed explanation of the formation of shrinkage cracks is given in Annex 1.

Differences in the soil-physics characteristics between marine clay areas affect the water-retention properties and the permeability and, in extreme cases, can produce large ripening cracks, which, in turn, lead to differences in denitrification capacity and thus the risk of nitrate leaching out in drainage water.

Pyrite
The mineral pyrite (FeS_2) occurs naturally in the subsoil in many areas in the Netherlands.
The formation and the occurrence of pyrite is related to the groundwater system and the geological structure of the subsoil. Pyrite mainly occurs in:
– deep subsoil and seepage areas in which clay and peat are present;
– fluvial deposits with a high content of organic matter (a maximum of several weight percentages);
– marine deposits.

In sandy infiltration areas, the circumstances for pyrite forming are not ideal; in these areas (virtually) no pyrite occurs.
The occurrence of pyrite in the subsoil can affect the quantity of nitrate that is available for leaching into the groundwater and surface water. Under anaerobic conditions, pyrite can reduce nitrate in accordance with chemical equation 1 and thus reduce the risk of nitrate leaching out.

$$2FeS_2 + 6NO_3^- + 4H_2O \Rightarrow 2Fe(OH)_3 + 3N_2 + 4SO_4^{2-} + 2H^+ \qquad 1)$$

Seepage
The influence of seepage on the nitrate concentrations measured in drainage water is not well known. Ammonium can be supplied in seepage water from deep streamlines. Seepage usually discharges directly or via drains into surface water. Because conditions along this route are not usually aerobic, no nitrification will occur, which means that seepage cannot be expected to constitute a significant source of nitrate. However, also the amount of upward seepage water can cause a diluting effect in case high nitrate concentrations from the root zone meet with relative low concentrations in upward seepage water.

Quantity of organic matter
The effect of the presence of organic matter in the soil is twofold and is co-determined by whether the organic matter is located in an anaerobic or in an aerobic layer.
If the stock of organic matter in farmland soil is mainly located in aerobic layers, it will be mineralised, the mineralised nutrients can subsequently leach out into the groundwater and surface water. If the stock of organic matter is located in anaerobic layers, it can have a positive effect on the denitrification of nitrate and as a result will reduce the amount of leaching. The effect of the presence of large stocks of organic matter (for example, peat layers) therefore also depends on the depth and the hydrological conditions (anaerobic or aerobic).

The division of discharge over drainage components
The precipitation surplus (precipitation minus evaporation) is not only discharged through the drainage system. Part of the surplus is also transported through the soil to discharge in ditches. The relationship between drain discharge and total discharge depends strongly on the local situation. In clay soils discharge mainly takes place through drain pipes, but in sandy (loamy) soils in particular, part of the discharge into ditches goes through the soil. In deep sandy subsoil, this can amount to more than 50%. Drainage can fracture clay soils, which increases their permeability (ripening). As a result, the drain discharge fraction of the total discharge will decrease. The decrease can, however, be expected to remain limited because most of the discharge will still take place through the drains.

In addition to the precipitation surplus, drains and ditches can also remove seepage from deeper layers. This seepage can be regional, or produced by local groundwater flows. If the clay layer is thicker than 3.0m, it can be assumed that no seepage water will enter the drains. However, this can be the case with thinner clay layers (Meinardi et al., 1997). The nature and volume of seepage water depends in each case on the local circumstances, which can vary per farm and per plot of land.

Groundwater table classes
Denitrification takes place under anaerobic conditions. Because of this, wet soils have a greater denitrification capacity than dry soils and land with a high groundwater level has a lower risk of nitrate leaching. However, if the groundwater level is too high, nitrogen can run over the topsoil and discharge into surface water.

Summarising:
In this paragraph, the sources, transport routes and processes that can play a role in the leaching of nitrate into groundwater and drainage water are described. Some sources only exert an influence in theory (ammonium in seepage water does not contributing to nitrate forming; pyrite from deeper in the soil profile not contributing to denitrification) and other factors have an ambiguous effect. Naturally occurring organic matter (such as peat layers) can under aerobic conditions (above the groundwater table) can contribute to nitrate leaching through mineralisation, while under anaerobic conditions it contributes to denitrification. On the one hand, hydrological processes lead to an accelerated discharge of nitrate into surface water and on the other hand provide anaerobic conditions allowing denitrification to take place.

3.3 Discussion and follow-up measures

Discussion items

Drainage water versus groundwater

The results of the exploratory data analysis show that nitrate concentrations in the groundwater are generally lower than nitrate concentrations in drainage water. The difference in nitrate concentrations between drainage water and groundwater are not only due to the origin of the water, but can probably also be explained by, for example, the soil type and land use, which are strongly correlated to the drainage components. The difference in sampling depth should also be taken into account: groundwater is on average sampled at a greater depth from the groundwater table than drainage water and can consequently have undergone stronger denitrification. In comparing nitrate concentrations between marine clay areas, the origin of the samples (groundwater versus drainage water) must therefore also be taken into account.

Division into regions

For the exploratory data analysis, the north-western and north-eastern marine clay areas were merged to form one region (northern marine clay area). The underlying motivation for doing this is that, in both areas, the nitrate concentrations are low (i.e. they do not exceed the EU-target). During the meeting of experts, the division into regions was brought up for discussion. The argumentation for this is that there may be variations in the clay mineralogy in the two areas resulting in different water-retention properties. This effects, in turn, the denitrification capacity and the risk of leaching into ground and
surface water.

Follow-up measures

The results of the exploratory data analysis indicate a need for additional analysis of the nitrate concentrations for the separate marine clay areas. The following phase of the study included, among other things, an investigation of whether the differences in nitrate concentrations measured between the marine clay areas were significant. Because the number of measurements in **groundwater** was relatively low and sampling 'only' started in 2002, these measurements were **not taken into consideration** during the rest of the study.

During the meeting of experts, it became apparent that none of the factors described in the conceptual framework could be excluded in advance as a matter of course. Further investigation of all the factors, working from global to fine data was recommended. Phase 1 started with an exploratory data analysis to obtain insight into whether any differences were visible between the separate marine clay areas. Following on from the discussion with the experts, phase 1 also paid attention to the question of whether any differences in the clay mineralogy, especially between marine and lagoonal clay, between the regions could be expected.

4 Results phase 1

4.1 Exploratory data analysis

The discussion during the meeting of experts indicated that, in the attempt to explain the differences in nitrate concentrations between marine clay areas, no factors could be excluded in advance. In this section, the results of the exploratory data analysis are presented.

Land use
Nitrogen losses can depend on the type of crop under cultivation. The information layers of the STONE-model were used to draw up an inventory of land use to obtain insight into whether there were differences in cultivated crops between the marine clay areas.

Land use in the STONE model is classified in four groups: grassland, maize, arable farming (and other agricultural crops) and nature. The distribution of the three agricultural land uses in the four marine clay areas is shown in Table 3.

Table 3
Land use percentage in the four marine clay areas.

Land use/region	Marine clay areas			
	North-eastern	North-western	South-western	Central
Grassland	51%	24%	9%	5%
Maize	1%	<1%	2%	1%
Arable farming	48%	76%	89%	94%

The inventory clearly shows that there are differences in land use between the four marine clay areas included in the study. The north-eastern marine clay area has the lowest percentage of arable farming and the central marine clay area the highest percentage of arable farming.

Clay mineralogy
To obtain insight into whether there were indications of differences in clay mineralogy between the separate marine clay areas, a limited literature study was carried out. For Friesland/Groningen (Wadden Sea area), West-Friesland and Zeeland (Schorren), relevant literature was found (Favejee, 1951 and Breeuwsma, 1985).

Groen (1997) provides information about the clay mineralogy of the soils of the IJsselmeer polders (Flevoland).

In Favejee's research, the mineralogical composition of sludge from the North Sea, the Wadden Sea, the estuaries of Zeeland and fluvial clay (Eems, Weser, Elbe and Rhine) was investigated. Breeuwsma analysed the clay mineralogy of marine clay (excluding the marine clay in the IJsselmeer polders), fluvial clay (Maas and Rhine) and brook clay (Eastern Netherlands). In addition to clay mineralogy, Breeuwsma's research also looked into the concentrations of 'free oxides' (SiO_2, Al_2O_3 en Fe_2O_3). The results of Favejee and Breeuwsma's research are given in Annex 2.

Favejee's analysis shows that no clear distinction can be made between sludge from the Wadden Sea, the Eastern and Western Scheldt, the bed of the North Sea and particles suspended in the water of tidal inlets. The results do, however, show that there is a clear difference between marine and fluvial sludge.

In his report, Breeuwsma only gives the mineralogical composition of the marine clay of Friesland/Groningen. The mineralogical composition of marine clay in Zeeland and West-Friesland is not discussed.

The results for the free oxides indicate that the marine clays in Friesland/Groningen, West-Friesland and Zeeland have similar compositions, but there are clear differences with river and brook clay.
In addition to clay mineralogy, the origin of the sediment was also studied. The results of this were all the same; the sands and sludge have a marine origin and were brought inland from the North Sea through tidal inlets in the Wadden Sea region and not deposited by the Ems, Weser, Elbe or Rhine rivers. Van Straaten (1954) indicates that this also applies to the sands in the estuaries of Holland and Zeeland. The sludge along the coast has a uniform composition.

Groen (1997) specifies that the three most important clay minerals in the IJsselmeer polders are illite (60%), kaolinite (20%) and montmorillonite (20%). He suggests that the first two do not exhibit any swell or shrinkage behaviour after ripening. Only montmorillonite allegedly does this. However, Bronswijk and Vermeer (1990) showed that clays in the Flevopolders do swell and shrink, especially in the topsoil.

On the basis of the limited amount of available relevant literature, we must assume that there are no differences between the mineral composition of the marine clay in Friesland/Groningen, West-Friesland (Noord-Holland) and Zeeland. Significant differences are not expected in Flevoland, apart from the formation of shrinkage cracks.

<u>Soil type</u>
Two separate maps were used to obtain insight into any variations in soil type: the 1:50,000 soil map and a superimposed soil-physics parameters map (PAWN soil units).

1:50,000 soil map
On the basis of the soil type (Code column in the 1: 50,000 soil map), soil types were selected that cover at least 4% of the separate marine clay areas (Figure 9 and Table 4). See Annex 3 for an explanation of the codes.

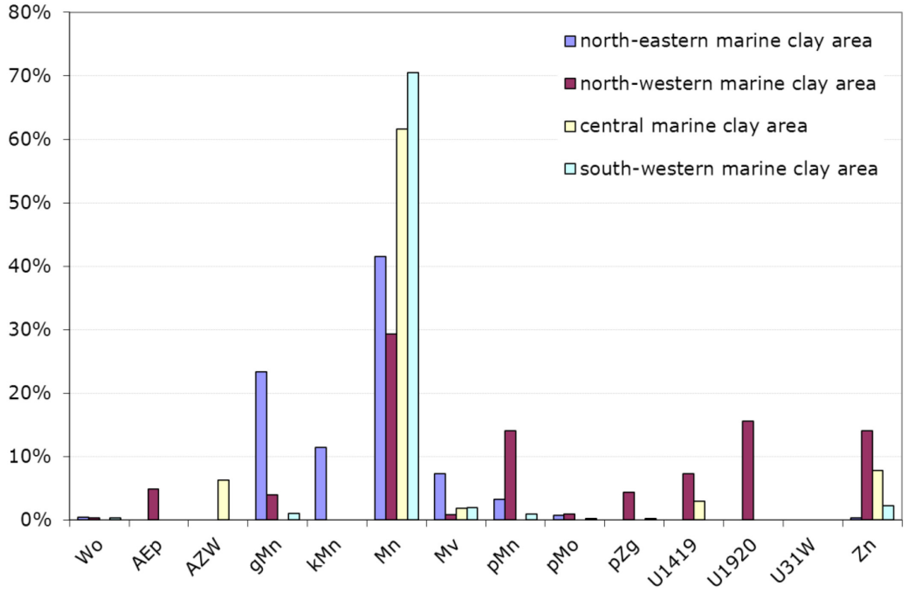


Figure 9
Soil types (soil map 1: 50000) occurring in more than 4% of the area in marine clay areas.

Table 4
Percentage occurrence of dominant soil types (> 10%) in the separate marine clay areas.

Area	**Dominant soil types**						
	Mn	**gMn**	**kMn**	**pMn**	**pMo**	**U1920**	**Zn**
North-eastern marine clay area	41.5%	23.4%	11.4%	3.3%	0.7%		0.3%
North-western marine clay area	29.3%	4.0%		14.1%	0.9%	15.6%	14.1%
Central marine clay area	61.6%			0.0%			7.8%
South-western marine clay area	70.5%	1.0%	0.0%	0.9%	0.2%		2.3%

Type Mn *(polder entisol with iron oxides and grey patches starting within 50 cm of the surface)* is the dominant soil type in all marine clay areas, but especially the central and south-western marine clay areas (> 60%). In the north-eastern marine clay area, type gMn *(infertile, polder entisol*, > 20%) occurs alongside type Mn. In the north-western marine clay area, the variation in soil types is greater than in the other areas.

Mn soil types are subdivided (Figure 10) according to lime content (rich in lime (A), lime-deficient (B) and non-calcic (C)). A further distinction is made on the basis of the lutum fraction in the topsoil:
- Light loam (1) ➔ 8-17% lutum
- Heavy loam (2) ➔ 17,5-25% lutum
- Light clay (3) ➔ 25-35% lutum
- Heavy clay (4) ➔ > 35% lutum

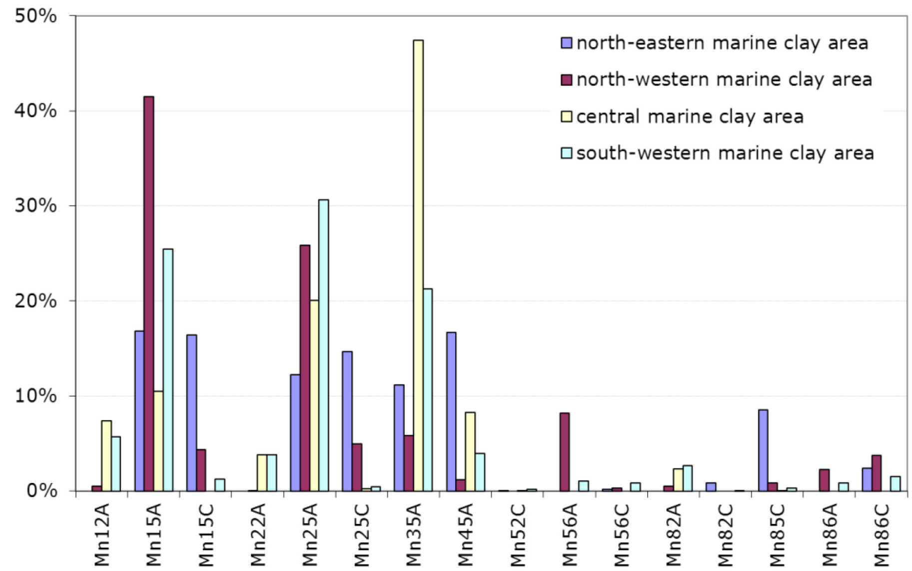


Figure 10
Percentage division of Mn soil types in the marine clay areas.

Table 5
Percentage occurrence of the dominant (> 10%) Mn soil type in the separate marine clay areas.

Area	**Dominant soil types**					
	Mn15A	**Mn15C**	**Mn25A**	**Mn25C**	**Mn35A**	**Mn45A**
North-eastern marine clay area	16.8%	16.4%	12.2%	14.7%	11.2%	16.7%
North-western marine clay area	41.5%	4.3%	25.9%	5.0%	5.8%	1.2%
Central marine clay area	10.5%	0.0%	20.0%	0.2%	47.4%	8.3%
South-western marine clay area	25.4%	1.3%	30.6%	0.4%	21.2%	4.0%

In general, the Mn soils in all clay areas are predominantly rich in lime (table 5). The soils in the north-eastern marine clay area are an exception in this respect and are largely non-calcic (C).
More than 40% of the north-western marine clay area consists of lime-rich, light loam soil. The central marine clay area is comprised mainly of lime-rich, light clay soil. In the south-western marine clay area lime-rich, light loam soil (25%), lime-rich heavy loam soil (31%) and lime-rich light clay soil (21%) occur.

PAWN soil units
Twenty-one soil-physics parameters (PAWN soil units, Klijn, 1997) were superimposed on the 1:50,000 soil map. This was based on the translation of the 1:250,000 soil map into soil-physics parameters (Wösten et al., 1988) as applied in the WSV schematisation. A total of seven soil-physics parameters are related to clay soils (Table 6).

Table 6
Characteristics of PAWN soil units 15 to 21.

Soil physics parameter	Description
15	Homogeneous loam soils
16	Homogeneous light clay soils
17	Clay soils with a heavy intermediate layer or subsoil
18	Clay soils on peat ('drecht' entisols/fluvents)
19	Clay on fine sand
20	Clay on coarse sand
21	Loam soils

The percentage distributions of the occurring PAWN soil units for the separate marine clay areas are shown in Figure 11 and Table 7. The Figure shows that the south-western and central marine clay areas (including Wieringermeer) have a significantly high percentage of soil unit 19 (clay on fine sand). It is also noticeable that PAWN soil unit 15 (homogeneous loam soil) is the most dominant type in all areas, apart from the central marine clay area (including Wieringermeer).

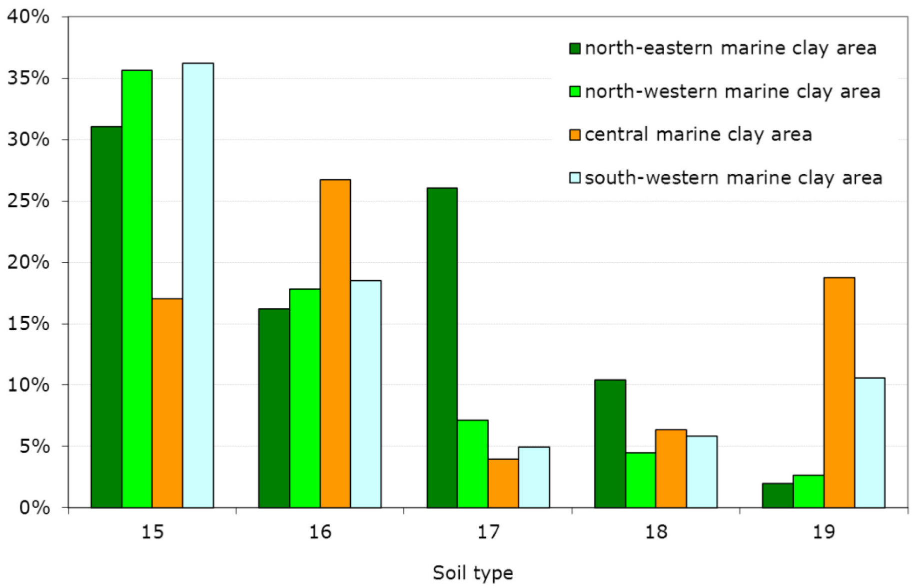


Figure 11
Percentage distribution of PAWN soil units over the four separate regions in marine clay areas and inland polders.

Table 7
Percentage occurrence of the dominant PAWN soil type in the separate marine clay areas.

Area	**Dominant soil types**					
	15	**16**	**17**	**18**	**19**	**20**
North-eastern marine clay area	31.0%	16.2%	26.1%	10.4%	2.0%	0.0%
North-western marine clay area	35.6%	17.8%	7.1%	4.5%	2.6%	0.2%
Central marine clay area	17.0%	26.7%	3.9%	6.4%	18.8%	0.0%
South-western marine clay area	36.2%	18.5%	4.9%	5.8%	10.6%	0.0%

<u>Pyrite</u>

Selection of geochemical data

The analysis of the presence or absence of pyrite in the soil layer extending one to two metres below surface level was carried out by Deltares. The results were presented in a report (Van Kempen, Griffioen, 2011). This paragraph contains a **summary** of the method and results. See the report for a more detailed description.

In the Netherlands, geochemical information is collated and grouped on the basis of the country's main geographical regions (Figure 12, Vermooten et al., 2005).

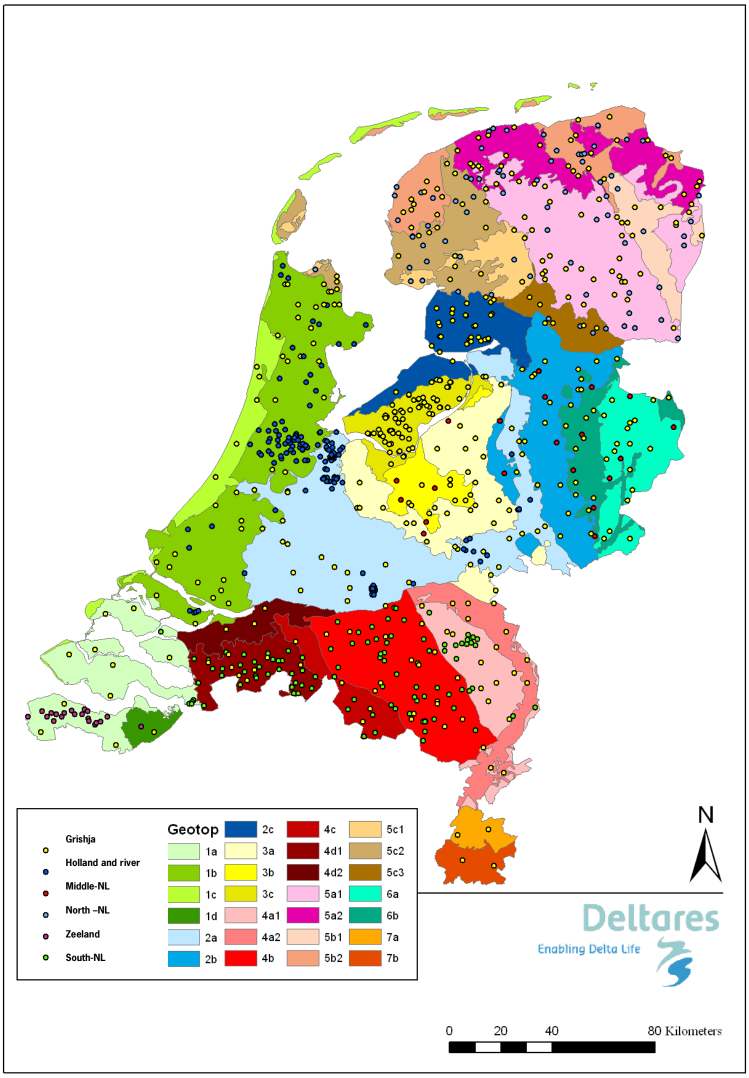


Figure 12
Data sets used in the different main geographical regions.

To determine the pyrite content, geochemical data on subsoil in the Netherlands was used, which was collected over the course of time in several studies (Figure 12). Annex 4 contains an overview of the used dataset separated per main geographical area and the maximum depth for which figures are available. The total number of samples included in the study was in excess of 8000. However, after selecting according to depth (1-2m below surface level) and analysis of pyrite content, 597 samples were left over.

Step 1
Before the pyrite content of the soils in the marine clay areas could be determined, whether the number of samples was sufficient from a statistical perspective to be able to make a reliable 'general' estimate for the all the areas combined. To this end, all the samples were categorised in units based on geographical main area and lithology (sand, clay/loam and peat).
In this way, the maximum of 75 different units (excluding main geographical areas 7a and 7b) were formed (Table 8).

For 25% of the units, no data on the occurrence of pyrite was available. For a further 23%, insufficient data was available to make a reliable statistical estimate. For the remaining units, the pyrite content could be calculated with some degree of certainty.

Follow-up measures

In order to make the estimates of pyrite content more accurate, the dataset was examined for optimisation possibilities as follows:

1) Whether areas with a similar shallow geology could be merged so that the statistical calculations could be based on more sample (step 2).
2) Which areas were most relevant for this study and should consequently be prioritised in the optimisation (step 3).
3) Whether it would be possible to use samples from greater depths (Holocene deposits) (step 4).

Table 8

Number of soil units (combination of main geographical area and lithology) for the various steps that can be taken to make a 'national' estimate of the pyrite content of the subsoil (1-2m below surface level).

Reliability	**Number of samples**	**Number of units (main geographical area + lithology)**			**Percentage**		
		Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
No data	-	19	17	-	25%	23%	-
Low	1 - 4	17	13	1	23%	17%	7%
Sufficient	5 - 9	13	14	5	17%	19%	33%
High	> 10	26	31	9	35%	41%	60%
Total		75	75	15	100%	100%	100%

The combination of areas (step 2) improved the results. However, if only the relevant areas are examined (step 3), it appears that almost all areas, except for one soil unit, are in the sufficient or high reliability classes. In step 4, whether the samples of Holocene deposits from depths of one to five metres could be used to determine the pyrite content of the subsoil at a depth of one to two metres. However, depth profiles indicated that this would not produce statistically reliable data.

On the basis of the results, it was decided to determine the pyrite content using samples from combined areas after applying the criterion that at least five samples had to be available for each soil unit.

Estimates of pyrite content

On the basis of the available data, the pyrite content of different soil units was calculated using formula 2 below:

$$\text{Pyrite} = M_{FeS2}/2M_S\ S \qquad 2)$$

in which the variable S stands for the sulphur content and M_X the molecular mass of the compound.

The average pyrite content of the relevant soil units (clay units) are given in Table 9; the statistical reliability is indicated by the respective colour (green = high, yellow = sufficient, orange = low). The average pyrite content for areas that were not relevant to the study are given in Annex 5.

Table 9

Number of samples and the average pyrite content of the subsoil (1-2m below surface level) for a number of top systems in the marine clay areas.

Top system	**Number of samples**			**Average**		
	Clay/Loam	Peat	Sand	Clay/Loam	Peat	Sand
1a, 1d, 4d2	15	2	6	0.41	1.88	0.27
1b	14	11	8	1.26	4.95	0.40
2c, 3c	45	34	11	0.98	2.64	0.21
5a2, 5b2	39	9	19	0.40	2.64	0.82
5c2	7	10	9	0.09	4.70	0.09

By multiplying the estimated pyrite content per unit with the peat, sand and clay fractions of the same unit, the probable pyrite content at 1 - 2 m below surface level can be calculated per grid cell measuring 250*250 m and displayed spatially (Figure 13).

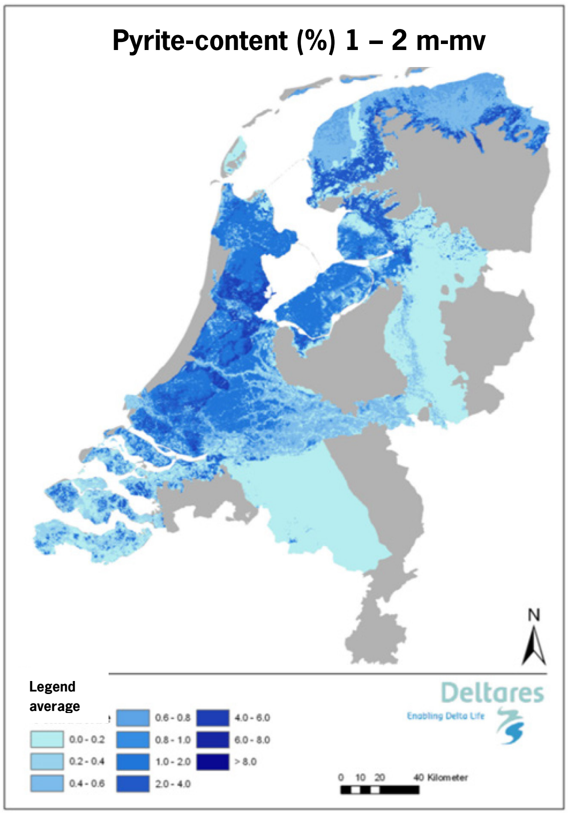


Figure 13

Estimate of the pyrite content at 1 - 2 m below surface level based on the average of the available data.

In the south-western marine clay area, the pyrite content at a depth of 1 - 2 metres is in general lower than the pyrite content of the north-eastern marine clay area. This is, in turn, lower than the pyrite content in the central marine clay area and large sections of the north-western marine clay area.

The highest pyrite content occurs in Noord-Holland in areas where there is a relatively large amount of peat. The peat-rich areas of Groningen, Friesland and Overijssel can, by analogy, also be expected to have the highest pyrite content.

Because there is less peat in the Holocene topsoil in Zeeland, the expected pyrite content will be lower here than in other parts of the country. This is also related to different geological formation of Zeeland during the Holocene period compared with the rest of the Netherlands. During the Holocene period, the south-western Netherlands consisted predominantly of the estuaries of the Scheldt, Maas and Rhine. A typical aspect of this period was the active peat formation that occurred in most parts of the Netherlands, except the Friesland/Groningen Wadden Sea area and the adjoining inland strip.

Seepage

The average seepage flux for the various marine clay areas can be determined by using the NHI seepage map (98-05, http://www.bosatlasvannederlandwaterland.nl/, http://www.nhi.nu/). The clay areas are divided into a number of sections; the calculated average seepage is shown in Figure 14 and Table 10.

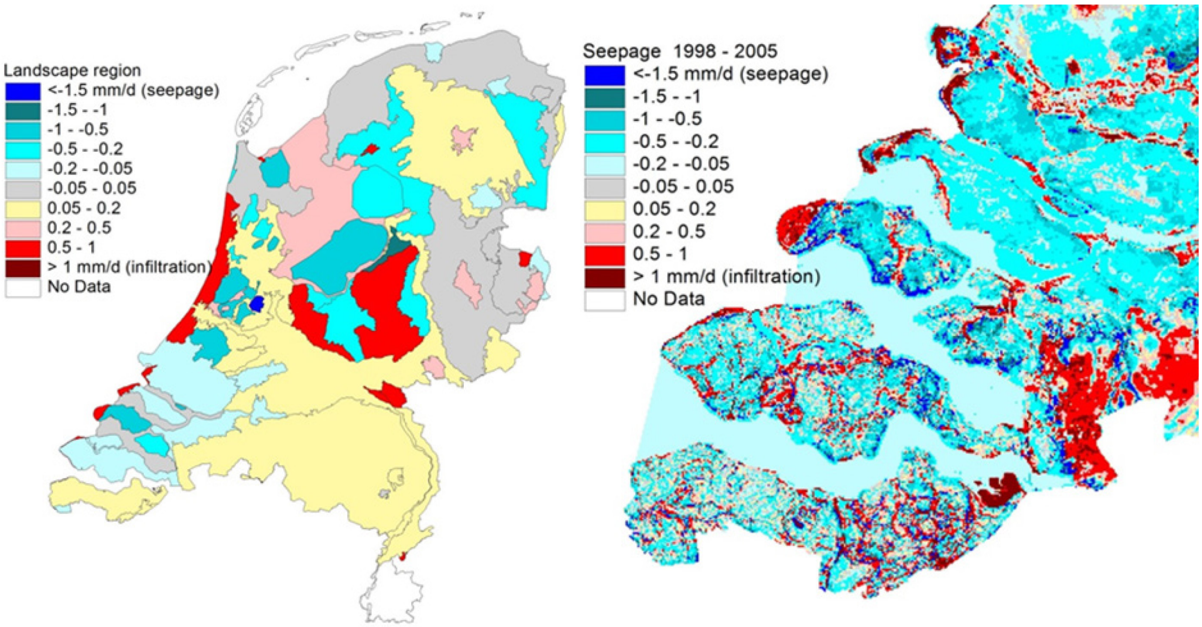


Figure 14
Average seepage per landscape region (left) and details of the seepage map for Zeeland (right).

Table 10
Seepage flux (mm/d) for the different areas.

Area	Min.	Max.	Average	STD
North-eastern marine clay area	-20.07	10.51	-0.01	0.37
North-western marine clay area	-36.90	6.72	-0.05	0.45
Central marine clay area	-44.30	47.20	-0.47	1.84
South-western marine clay area	-26.84	30.36	-0.09	0.87

Upward seepage is indicated by a negative value; a positive value indicates downward seepage or groundwater table subsidence. Net (upward) seepage occurs in all the marine clay areas (negative value). However, the distribution in the flux (upward seepage/downward seepage) is large. In all marine clay areas, seepage and subsidence occur.
The average seepage in the north-western and northern-eastern marine clay areas is lower than in the other areas. The central marine clay area has the highest average seepage. The south-western marine clay area has a large variation in seepage values. Whether a large or small amount of seepage or even subsidence occurs (for example, creek ridges) depends heavily on where a sample is taken.

Groundwater table (Gt-class)
The 1:50,000 soil map was also used to determine the spread of groundwater table classes (Figure 15). The high percentage of Gt-class V (46%) in the north-eastern marine clay area is significant. The high percentages of Gt-class VI in the south-western (more than 63%) and the central marine clay areas (46%) are also noticeable.
The Gt-classes were subsequently clustered into three categories on the basis of the GHG (Table 11).

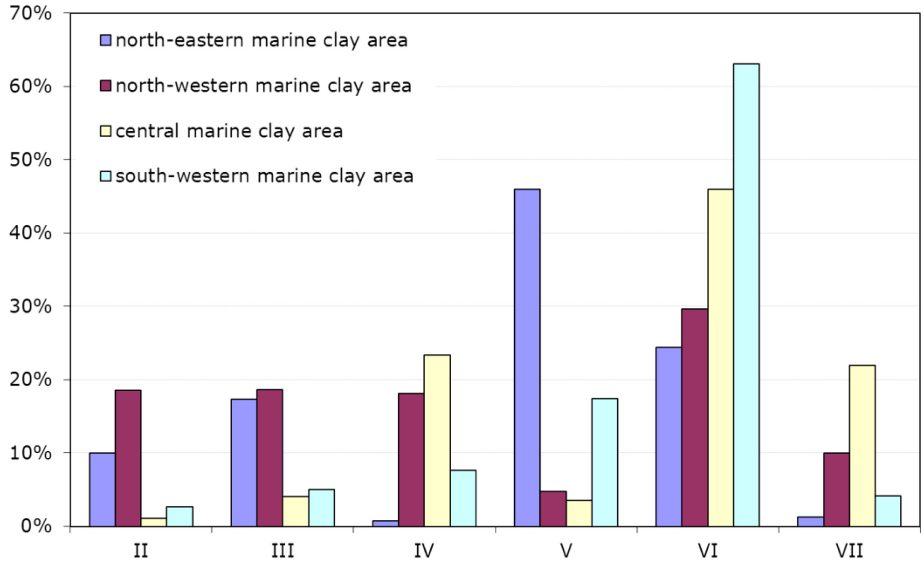


Figure 15
The spread of groundwater tables in the different marine clay areas.

Table 11
Categorisation of groundwater table classes in 'wet', 'moderately dry' and 'dry' clusters.

Cluster	Gt classes
Wet	I, II, III and V
Moderately dry	IV and VI
Dry	VII

The category ‘wet’ is dominant in the north-eastern marine clay area (> 73%); the category ‘moderately dry’ is dominant in the other marine clay areas, although the category ‘wet’ also frequently occurs in the north-western marine clay area (42%). In the central marine clay area, the percentage of clusters in the category ‘dry’ (22%) is higher than in the other marine clay areas (table 12).

Table 12
Spread of Gt-classes (an clusters of Gt classes) in the different marine clay areas.

Area	**Gt-classes**					
	II	**III**	**IV**	**V**	**VI**	**VII**
North-eastern marine clay area	10.0%	17.4%	0.7%	46.0%	24.4%	1.3%
North-western marine clay area	18.6%	18.6%	18.2%	4.8%	29.7%	10.0%
Central marine clay area	1.1%	4.0%	23.4%	3.5%	46.0%	21.9%
South-western marine clay area	2.6%	5.0%	7.6%	17.4%	63.1%	4.1%
	Wet		Moderately dry		Dry	
North-eastern marine clay area	73.4		25.1		1.3	
North-western marine clay area	42.0		47.9		10.0	
Central marine clay area	8.6		69.4		21.9	
South-western marine clay area	25.0		70.7		4.1	

Organic matter
Under aerobic conditions, organic matter contributes to the nitrogen load (mineralisation). Under anaerobic conditions, organic matter contributes to denitrification (energy for organisms). De Vries (1999) characterised the layer structure of the units in the Soil Map of the Netherlands (1: 50,000) according to relevant physical-chemical features including the organic matter content. This data applies to the soil profile to a depth of 1.20 m and takes land use into account. For the characterisation, data from the Soil Information System (BIS) and information in the key to the Soil Map of the Netherlands, scale 1:50,000.

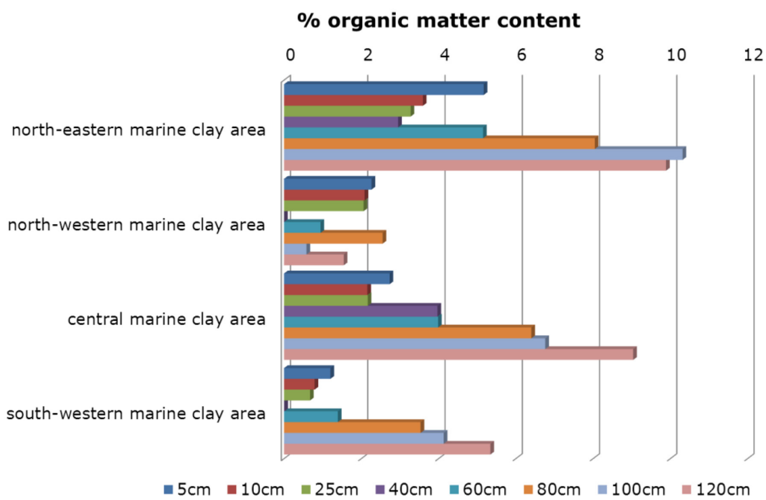


Figure 16
Average organic matter content spread over the soil profile in the four marine clay areas.

The lowest organic matter content is found in the north-western marine clay area; the average over the soil profile is < 2.5%, and 1.5% at 120 cm below surface level (Figure 16). In the north-eastern, central and south-western marine clay areas, there is a progressive increase in organic matter content in line with depth. At 120 cm below surface level, the organic matter content is approx. 10% in the north-eastern marine clay area; approx. 9% in the central marine clay area and 5% in the south-western marine clay area.

In conclusion, there are three distinct groups for the organic matter content at 120 cm below surface level: *low* (1.5%, north-western marine clay area), *average* (approx. 5%, south-western marine clay area) and *high* (9-10%, north-eastern and central marine clay areas). Annex 6 contains the spatial distribution for the Netherlands for the layers 5, 10, 25, 40, 60, 80, 100 and 120 cm below surface level).

Summarising:
For a complete overview, the results of the exploratory data analysis were placed side by side (Table 13). The results of the clay mineralogy were not included because no differences in clay mineralogy between the marine clay areas are to be expected on the basis of the (limited amount of) literature.

Table 13
Overview of the differences in the most important characteristics between the marine clay areas.

	Dominant characteristics						
	Land use	Pyrite content	Seepage [2] mm/y	Soil type	PAWN soil	Gt class	Organic matter content
North-eastern marine clay area	Grassland (51%)	Central	-3.7	Mn [1] (41.5%)	15 (31.0%)	V (46.0%)	High
North-western marine clay area	Arable farming (76%)	High	-18	Mn [1] (29.3%)	15 (35.6%)	VI (29.7%)	Low
Central marine clay area	Arable farming (94%)	High	-172	Mn [1] (61.6%)	16 (26.7%)	VI (46.0%)	High
South-western marine clay area	Arable farming (89%)	Low	-33	Mn [1] (70.5%)	15 (36.2%)	VI (63.1%)	Central

1) Polder entisols with rust and grey patches starting within 50 cm of the surface

2) Negative value is net seepage, positive value is net drainage

- The average pyrite content in the south-western marine clay area is low compared with the other marine clay areas. The highest average pyrite content occurs in the north-western and central marine clay areas. The analysis shows that areas in which peat occurs in the subsoil have a higher pyrite content;
- In all the marine clay areas, **net** seepage occurs. The average **net** seepage in the central marine clay area (172 mm/year) is higher than the average seepage in the other areas (4-33 mm/year). There is a large amount of variation within areas (due to zones of groundwater table subsidence);
- Soil type Mn is dominant in all the areas. This applies particularly to the central and south-western marine clay areas (> 60%). If the soil type is further characterised according to lutum content (loam versus clay), it

becomes apparent that in the lutum content is lower in the south-western marine clay area (almost 60% loam) than in the central marine clay area (almost 60% clay);
- The dominant PAWN soils are 15 (homogeneous loam) and 16 (homogeneous, light clay). This matches the soil types indicated in the 1:50,000 soil map. However, the analysis also shows that PAWN soil 19 (clay on fine sand) is relatively more common in the central and south-western marine clay areas than in the other marine clay areas;
- If the GHG is taken as a starting point, the north-eastern marine clay area generally has a dryer Gt class than the other marine clay areas.
- The organic matter content in the north-eastern and central marine clay areas at approx. 120 cm below surface level is higher than it is in the south-western marine clay area. The lowest organic matter content is found in the north-western marine clay area.

The results therefore show that there are differences in the (individual) regional characteristics of the marine clay areas. However, there is also a large amount of variation within marine clay areas. This means explaining the higher nitrate concentrations in the south-western and central marine clay areas compared with the other marine clay areas on the basis of the exploratory data analysis remains difficult. Additional analyses on a farm level are needed to be able to do this.

4.2 Farm-level analysis: nitrogen surplus of the soil balance

In order to determine whether there is a significant relationship between the nitrogen surplus of the soil balance and nitrate concentrations measured on a farm level, a statistical regression analysis was performed using the LEI/RIVM database. To do this, nitrogen surplus of the soil balance figures (on farm level) calculated by the LEI for the LMM test locations were used (source: LEI data) and the nitrate figures (farm average) from the RIVM database (source: RIVM/LMM).

A farm's nitrogen surplus of the soil balance is defined as follows:
The nitrogen surplus in the soil balance per hectare cultivated land. The nitrogen surplus is calculated as the surplus on the farm's balance (sum of all input minus the sum of all output) plus the supply of nitrogen from deposition, mineralisation and N-binding (legumes) minus N in calculated ammonia emissions from livestock accommodation/grazing and the storage/spreading of manure.

<u>Selection</u>
Before carrying out the regression analysis, the relevant farms were selected from the database. The following selection criteria were used in this respect:
- LMM farms in de marine clay areas (i.e. excluding farms in fluvial clay areas) which were subsequently further subdivided into four regions:
  - south-western marine clay area: Zeeland, Noord-Brabant and Zuid-Holland
  - central marine clay area: Flevoland
  - north-eastern marine clay area: Groningen and Friesland
  - north-western marine clay area: Noord-Holland
- Sample type:
  - drainage water
- Study years 2006-2008 (with sampling surveys in consecutive winter periods (2006/2007, 2007/2008 and 2008/2009).

Nitrate concentrations
After the selection procedure, a total of 83 farms were analysed. For 67 farms, samples were available for each of the three years (2006, 2007 and 2008); for ten farms, samples were available for two years and, for six farms, samples were only available for one year (table 14).

Table 14
Number of farms in the different marine clay areas that were included in the statistical analyses.

Area	Number of farms		
	2006	2007	2008
Central marine clay area	6	4	6
South-western marine clay area	21	21	20
North-western marine clay area	6	9	10
North-eastern marine clay area	40	42	42

The nitrate concentrations (mg/L) measured in the drainage water at the LMM farms are shown in Figure 17; the fine lines indicate the minimum and maximum measured nitrate concentrations, the 25 and 75 percentages by the rectangles (green and blue, respectively) and the red dots indicate the average nitrate concentration.

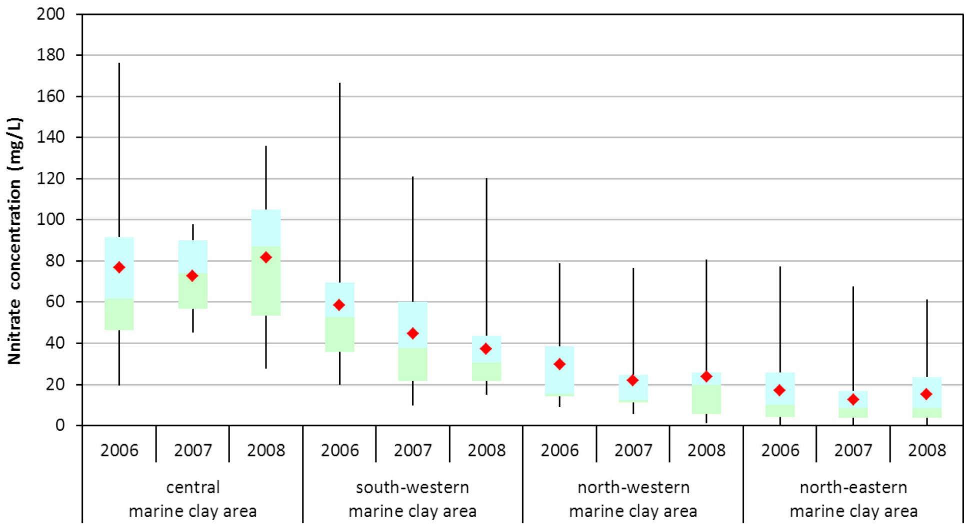


Figure 17
The spread of nitrate concentrations (mg/l) measured at LMM farms in the different marine clay areas.

In each year of the study, the average nitrate concentrations in the central marine clay area were above 50 mg/L. In the south-western marine clay area, the average nitrate concentrations only exceeded the 50 mg/L norm in in 2006, in 2007 and 2008, the average nitrate concentrations were below the norm. The average nitrate concentrations for the north-western and north-eastern marine clay areas are roughly the same and lower than in the central and south-western marine clay areas.

Regression analysis
The histograms of nitrate concentrations in the drainage water for 2006/2007 for the LMM farms in the south-western, central and north-eastern marine clay areas are shown in Figure 18. In order to limit the number of statistical calculations, it was decided not to include the north-western marine clay area. This was justified by the small number of measurements taken in this area.

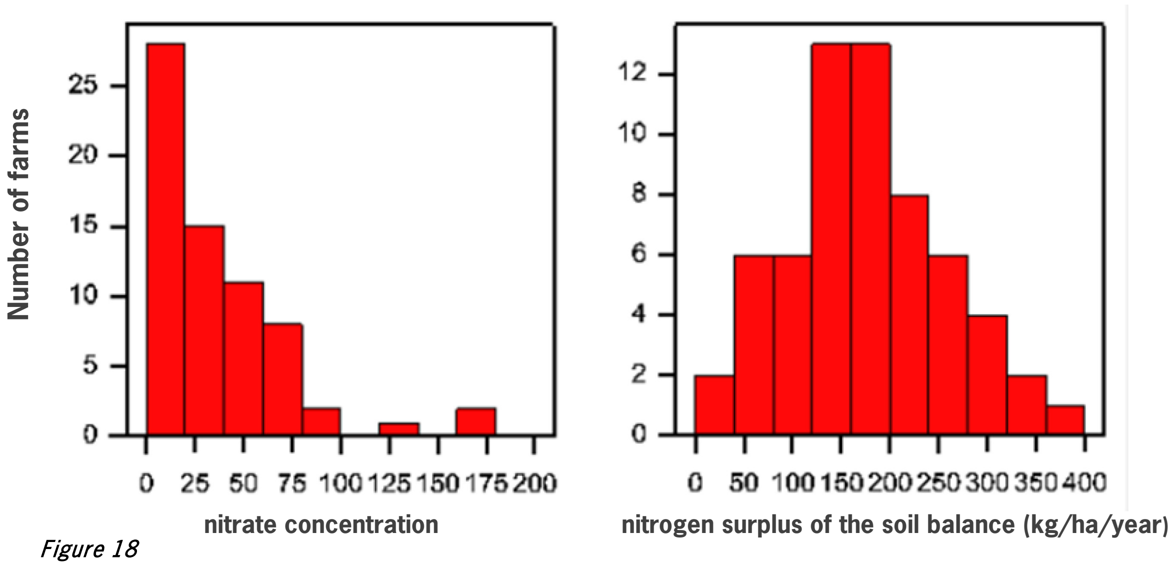


Figure 18
Spread of nitrate concentrations for LMM farms in the south-western, central and north-eastern marine clay areas in the survey year 2006.

In both figures the y-axis represents the number of farms in a specific class (x-axis). The figure on the left shows the spread of nitrate concentrations (mg/l) and the figure on the right the nitrogen surplus of the soil balance at farm level. Figure 18 shows that the spread in nitrate concentrations slopes to the left while the nitrogen surplus of the soil balance is evenly divided. The spread of nitrate concentrations and nitrogen surplus of the soil balance for the other survey years (2007 and 2008) are approximately the same as 2006 and are given in Annex 7.

Before determining the relationship between the average nitrate concentrations and the nitrogen surplus of the soil balance at the LMM farms, the nitrate concentrations were transformed to logarithms (the natural logarithm was used for this). This was done to enable to regression analysis to focus on the concentration ratios instead of differences. In addition, transforming to logarithms is a better way of meeting an important assumption of regression - the homogeneity of variations. The nitrogen surplus of the soil balance is spread fairly symmetrically and is not transformed.

The relationship between the nitrate concentrations and the nitrogen surplus of the soil balance was determined with and without the regional effect (Figure 19). 'Regional effect' means viewing the relationships between nitrogen surplus of the soil balance and nitrate concentrations per dataset for a given region. The differences between, in this case, three relationships is called the regional effect.

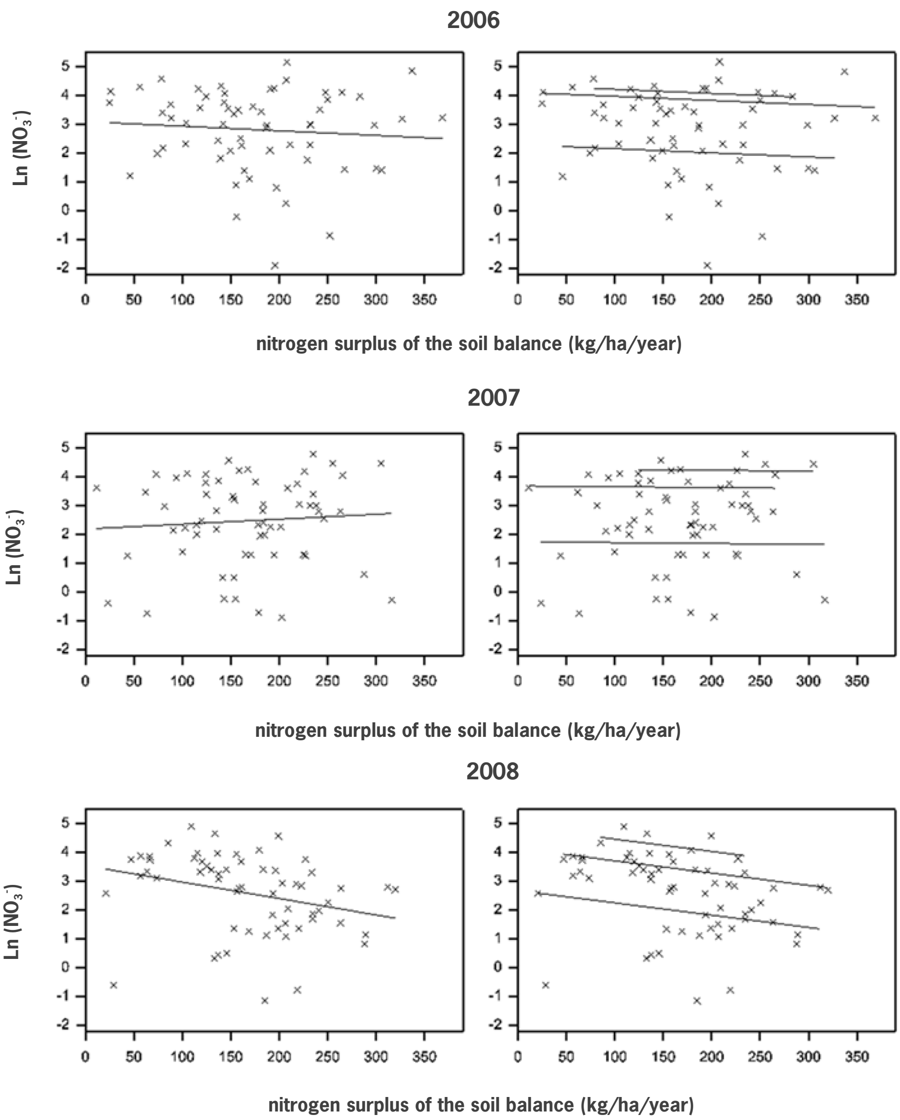


Figure 19
Regression relationship between Log NO_3 (y-axis) and the nitrogen surplus of the soil balance (x-axis) per year. The regional effect is not included in the figure on the left, but the figure on the right does include it.

Table 15
Results of the statistical analysis to determine the relationship between the regional effect and the nitrogen surplus of the soil balance on the one hand and the measured nitrate concentrations on the other hand.

Year	p values Regional effect	Estimated nitrogen surplus of the soil balance	p values
2006	< 0.001	-0.00143	0.43
2007	< 0.001	-0.00029	0.895
2008	< 0.001	-0.00426	0.032

The analysis (Table 15) shows that the regional effect is always very significant (p-values < 0.001). The relationship between the nitrogen surplus of the soil balance and measured nitrate concentrations for 2006 and 2007 was not significant (p-values > 0.05). In 2008, a significant relationship was found (p = 0.032), but it is negative. A negative relationship between the nitrogen surplus of the soil balance and nitrate concentrations measured in the drainage water cannot be systematically explained and was rejected for this reason.

On the basis of the analysis, the following conclusions were drawn:
- The nitrate concentrations in the north-eastern marine clay area are significantly lower than the nitrate concentrations in the south-western and central marine clay areas. The differences between the south-western and central marine clay areas are not significant.
- The results show that the nitrogen surplus of the soil balance on a farm level does not explain the nitrate concentrations measured of those farms in the marine clay areas.

4.3 Discussion

Exploratory data analysis
In order to portray the characteristics of the marine clay areas, various source files were used (Table 16).

Table 16
Overview of the source files used for the exploratory data analysis.

Physical environment factors	Sources
Clay mineralogy	Literature study
Pyrite content	Geochemical subsoil data (TNO)
Seepage flux	NHI seepage map
Soil type	1:50,000 soil map
	PAWN soil map (derived from the national soil map)
Groundwater table	1:50,000 soil map
Quantity of organic matter	Soil Science Information System (BIS)
	1:50,000 soil map

When interpreting the differences, the following points must be taken into consideration:
- No literature was found in which the clay mineralogy of all the marine clay areas was examined in the same way. The central marine clay area was not included in the research carried out by Favejee (1951) and Breeuwsma (1985), which means it is difficult to indicate whether the clay mineralogy of the central marine clay area deviates from the other areas. This is important because the highest nitrate concentrations were measured in the drainage water of the central marine clay area.
- Not all the listed sources are documents that cover all the Netherlands. This especially affected the method for determining pyrite content. For a number of clay areas, the amount of data on the pyrite content of the subsoil at a depth of 1-2 m below surface level is limited. In order to make the estimates more accurate, the dataset was optimised.

Farm-level analysis: nitrogen soil surplus
The results of the regression analysis show that there is no significant **positive** relationship between the nitrogen soil surplus and nitrate concentrations in drainage water on a farm level. When interpreting the data, the following points must be taken into consideration:

- Because the number of measurements in the north-western marine clay area were limited and because the de nitrate concentrations are low, it was decided to exclude this marine clay area from the results. This choice was arbitrary.
- The number of participating farms in the central marine clay area was limited.
- In calculating the nitrogen soil surplus, the *nature* of the surplus was *not* taken into account. There can be large differences in input ratios (the ratio between manure-N and artificial fertiliser-N) between areas and farms.
- The extent to which the nitrogen soil surplus leaches out differs from crop to crop. The leaching from clay arable farmland has approximately 3 times more leaching that clay grassland (Fraters et al., 2007). The land use must therefore also be taken into consideration.
- Furthermore, the extent of grazing is also believed to influence the rate at which the nitrogen soil surplus leaches out (Bouman and Fraters, 2011).

5 Results phase 2

5.1 Statistical analysis

In phase 1 *no* significant **positive** relationship between the nitrogen surplus of the soil balance on farm level and the average nitrate concentrations in the drainage water on the LMM farms was found, as a result of which phase 2 was initiated.
It is evident from the initial data-analysis that there are obvious differences in the amount of seepage water, pyrite content, soil type, groundwater table class and organic matter content between the marine clay areas, but that there is also a large amount of variation within the marine clay areas themselves. Based on the (limited) literature, it can be assumed that there are no differences between the clay-mineral composition of the marine clay in Friesland/Groningen, West-Friesland (Noord-Holland), Zeeland and Flevoland.

In order to make a reliable statistical analysis of the relationships between nitrate concentrations and the characteristics of the LMM farms, it is essential that this is based on raw data, meaning on a farm level. It was recommended that the necessary data were collected locally (i.e. on the LMM-farm) in combination with nitrate measurements (taken from the same respective plots). However, in view of the available time for completing the project and the related costs, setting up a measuring plan of this kind was not feasible and consequently a different approach had to be chosen.

In phase 2, with the exception of the clay mineralogy, the characteristics of the LMM farms were defined on the basis of various data files and maps (soil map, pyrite-map, NHI seepage maps and a map specifying the stocks of organic matter at various depths). The physical-environment factors of the LMM farms are stored in a database and used for a statistical analysis. The regression analysis involved examining the relationship between nitrate concentrations on the one hand, and the <u>groundwater level</u>, <u>soil type</u>, <u>seepage</u>, amount of <u>organic matter</u> and <u>pyrite</u> on the other hand, for the 2006-2008 period. The form of <u>land use</u> was also included as an explanatory variable.

Various sources of information were used to collect the farm characteristics and physical-environment characteristics of the LMM farms. However, a number of these characteristics can be clustered in various ways. This paragraph provides a brief description of the various sources of information/cluster methods and explains which sources/clustering were used, along with the results.

5.1.1 Data collection

<u>Groundwater table</u>
Two sources of information are available for the determination of the groundwater table:
1) Groundwater table per farm as entered in the RIVM database;
2) Groundwater table per farm on the basis of the 1:50.000 soil map.

The dominant groundwater classes (meaning the classes with the highest fraction) were determined per LMM farm for both of the data files and then sub-divided into three categories: wet (I-III*, V and V*), moderately dry (IV and VI) and dry (VII-VIII).

Table 17
Groundwater characteristics (wet, moderately, dry) of the LMM farms on the basis of the LEI/RIVM database and on the basis of the 1:50.000 soil map.

Gt class	RIVM database		1:50.000 soil map	
	Number of farms	Percentage	Number of farms	Percentage
Wet	42	62%	40	59%
Moderately dry	24	35%	26	38%
Dry	2	3%	-	-
Unknown	-	-	2	3%
Total	**68**	**100%**	**68**	**100%**

A total of 68 farms were included (Table 17). Based on the RIVM database, 42 farms (62%) belong to the category 'wet'. The other farms are mainly in Gt class IV or VI (35%). Two farms belong to the category 'dry'. The differences are minimal (a few per cent) if the 1:50.000 soil map is used.

<u>Soil type</u>
Two sources of information can be used in determining the (dominant) soil type per farm:
1) 1:50.000 soil map.
2) Classification on the basis of the PAWN soil map.

Soil map (1:50.000)
A total of 37 soil types are distinguished between on the basis of the 1:50.000 soil map (Annex 3). It was decided to divide these 37 soil types into classes because of the limited number of farms per soil type. Two options were considered:
1) The farms are divided into six classes on the basis of the type of soil (sand, peat, peaty, clay and other), in which the marine clay soils are divided into marine clay and 'gleyic' clay (Table 18, Annex 3).
2) The farms are sub-divided into three categories in which the classes 1, 2, 3 and 6 from cluster 1 are combined (Table 18).

Table 18
Dominant soil type at the LMM farms based on the 1:50.000 soil map, containing 6 classes and 3 categories.

Class	**Category**	**Soil type**	**Number of farms**			**Percentage**		
			2006	2007	2008	2006	2007	2008
1	1	Sandy soils	4	3	3	6.0%	4.5%	4.4%
2	1	Peaty and enk earth soils	1	1	1	1.5%	1.5%	1.5%
3	1	Peat soils and entisols	4	4	4	6.0%	6.0%	5.9%
4	2	Marine clay	34	35	35	50.7%	52.2%	51.4%
5	3	Gleyic clay	18	20	20	26.9%	29.9%	29.4%
6	1	Other (cluster)	4	4	4	6.0%	6.0%	5.9%
x	x	Unknown	2	-	1	3.0%	-	1.5%
Total			**67**	**67**	**68**			

Marine clay is the dominant soil type at more than 50% of the farms; 'gleyic' clay is the dominant soil type at approx. 30% of the farms.

PAWN soil
In addition to the classification on the basis of the soil map, the dominant PAWN soil was determined for each farm. A distinction is made between a total of 23 PAWN soils. It was also necessary/desirable to combine a number of PAWN soils in this case as well (Table 19).

Table 19
Dominant PAWN soil units at the LMM farms on the basis of the 1:50.000 soil map, containing 7 classes.

Class	**PAWN soil unit**	**Description**	**Number of farms**		
			2006	2007	2008
1	1-13	Sandy and peat soils	7	6	7
2	15	Homogenous sandy clay soils	24	25	24
3	16	Homogenous, light clay soils	9	10	9
4	17	Clay soils with a heavy intermediate layer or subsoil	16	19	19
5	18	Clay soils on peat ('drecht' entisols)	4	3	3
6	19	Clay on sandy soils	3	3	4
7	22-23	Water and paved	2	1	1
x	unknown	-	2	-	1
Total			**67**	**67**	**68**

PAWN soil units 14, 20 and 21 are not found at the LMM farms. The soil-physical units 22 and 23 are not taken into consideration here because they stand for open water and urban region, respectively.
The PAWN soil units 17 and 18 were combined for the ultimate regression analysis because there were too few measurements for type 18. The PAWN soil units 1 to 13 (peat and sandy soils) are both regarded as non-clay soils.

The choice between a classification according to the soil map or according to the PAWN soil units was based on the results of a regression analysis, carried out using the 'All possible subset selection' in which both variables are considered a possible predictor of the measured nutrient concentrations, including and excluding the regional effect (Table 20).

Table 20
Results of the statistical analyses in which the relationship between the measured nitrate concentration in the drainage water and the soil type at the LMM farms is examined. The soil type was determined on the basis of the 1:50.000 soil map or on the basis of the PAWN soils.

Year	**2006**		**2007**		**2008**	
	Adjusted [1] %	P-value	Adjusted [1] %	P-value	Adjusted [1] %	P-value
Soil type						
Soil map	28.18	0.000	23.66	0.001	28.61	0.000
PAWN soil map	21.27	0.002	17.14	0.005	21.21	0.002
Soil map + Regional effect	Form of land use.14	0.077	47.33	0.047	45.49	0.063
PAWN soil map + Regional effect	53.27	0.017	47.96	0.100	50.72	0.009

1 The term adjusted indicates which percentage (%) of the variance in nitrate concentrations can be explained

If the soil type is considered as explained variable (excluding the regional effect), then the percentage explained variance for classification on the basis of the 1:50.000 soil map is around 7% higher than the classification on the basis of the PAWN soil map (Table 20). Depending upon the year, 24 to 29% of the variance in nitrate concentrations can be explained by the soil type on the basis of the 1:50.000 soil map. This percentage is 17-21% based on the PAWN soil map. Both variables are significant. If the regional effect is also taken into account, then the percentage explained variance is higher for both variables, namely 45-47% on the basis of the 1:50.000 soil map and between 47-53% for the PAWN soil map.
The variable on the basis of the 1:50.000 soil map is not, however, significant in 2006 and 2008, whereas it is not significant for the PAWN soil map in 2007. Based on the results above, it was decided to go for the option in which the soil type is determined on the basis of the PAWN soil map.

Seepage
Use was made of the NHI-seepage map (98-05, http://www.bosatlasvannederlandwaterland.nl/, http://www.nhi.nu) in determining the amount of seepage water at the LMM farms. The average seepage flux (mm/day) was used in the regression analysis. It must be considered in this respect that the seepage flux within a farm can vary between a negative values (upward seepage) to a positive value (downward seepage).

Organic matter
The information regarding the organic matter content has been derived from the *Soil Map of the Netherlands* (1: 50,000) and the accompanying documentation to the map (F. de Vries, 1993 and 1999). So-called profile sketches were drawn up per soil unit in which a selection of information was made from the *Soil Information System (BIS)*. The profile sketches provide a description of the soil layer structure to a depth of 120 cm . They contain information per horizon on the median (50-percentile, P50), minimum (P10) and maximum (P90) value for the organic matter content, lutum content, loam content, sand coarseness (M50) and the pH. In addition, the median values for the calcium content, iron content, C/N-quotient and the density are also provided.

Pyrite
The pyrite map that was generated in phase 1 (paragraph 4.1.1) was used for the determination of the average pyrite contents.

Land use
Supplementary to the physical-environment factors above, analyses were also conducted in which it was examined whether there is a significant relationship between the land use and the measured nitrate concentrations. There are two possible options for determining the land use at the LMM farms:
1) Based on the farm type (arable land, dairy stock, high yield animals, other and non-LMM);
2) Based on the dominant land use expressed in the percentage (grassland, maize, arable land).

The choice for one of the two options was determined, as was the case with the soil type, by using a regression analysis (Table 21).

Table 21
Results of the statistical analyses in which the relationship between the measured nitrate concentration in the drainage water and the land use (farm type versus land use) at the LMM farms is examined.

Year	**2006**		**2007**		**2008**	
	Adjusted [1] %	P-value	Adjusted [1] %	P-value	Adjusted [1] %	P-value
land use						
Regional effect	45,22	0,000	43,18	0,000	43,18	0,000
Farm type	15,91	0,003	17,94	0,001	32,95	0,000
Land use	20,78	0,000	31,04	0,000	36,47	0,000
Farm type + Regional effect	53,09	0,007	52,34	0,002	58,90	0,000
Land use + Regional effect	52,31	0,004	59,31	0,000	60,61	0,000

1 The term adjusted indicates which percentage (%) of the variance in nitrate concentrations can be explained.

The variable land use is significant for both options, even if the regional effect is taken into account. Based on the results, we opted for land use on the basis of the area of grassland, maize and arable land, and not the farm type.

5.1.2 Regression analysis

The regression analysis is conducted with 'all possible subset selection'. This involves adjusting and sorting **all** possible regression models on the basis of the percentage explained variance for the different years (Annex 9). The 'best' models, being the models in which **all** of the variables are **significant** in **all** of the years, are shown in table 22.

Table 22
Explained variance (%)for the measured nitrate concentrations in the drainage water for a number of regression models in which all of the variables (=characteristics of the LMM farms)are significant for all of the years.

Year	**Percentage explained variance (%)**			
	2006	**2007**	**2008**	**2006-2008**
1 variable				
% grassland	28	41	47	39
% other	21	31	37	30
groundwater table	25	21	29	26
PAWN soil	21	17	21	22
Upward seepage	8	6	6	8
2 variables				
% grassland + Upward seepage	38	52	57	49
% grassland + % other	38	48	54	46
% grassland + groundwater table	34	46	55	45
% other + Upward seepage	32	43	48	42
PAWN + groundwater table	41	30	46	41
% other + groundwater table	30	40	49	40
3 variables				
% grassland + % other + Upward seepage	43	56	62	54

1 The term adjusted indicates the percentage (%) of the variance in the nitrate concentrations that can be explained.

Based on the percentage explained variance, the 'best' results are achieved with the model with the % grassland, % other (arable land, exclusive maize) and the amount of upward seepage water. Depending upon the year, it is possible to explain 43% to 62% of the variance in the measured nitrate concentrations using these three factors. Based on the p-values for this model (Table 23), it is evident that the % grassland is most significant, followed by the amount of seepage water.

Table 23
Results of the statistical analyses for the 'best' model.

Year	P-value			
	2006	2007	2008	2006-2008
% grassland	0,002	0,000	0,000	0,000
Upward seepage	0,019	0,001	0,001	0,000
% other	0,022	0,013	0,006	0,000

The results also show that the variables *nitrogen surplus of the soil system*, *organic matter content* and the *pyrite content* are lacking in the table above. This means that *no* model is derived of which the variables are significant in **all** three years; these variables may however be significant if these years are considered separately (see Annex 9).

Conclusions
The following conclusions can be drawn on the basis of the regression analysis:
- there are no indications that differences in the nitrogen surplus of the soil system, organic matter content and the pyrite content provide an explanation for the nitrate concentrations measured in the drainage water and therefore explain the differences in the nitrate concentrations between the LMM farms;
- The 'best' model is the model with the variables % grassland, % arable land (exclude maize) and the seepage flux (54% explained variance for the years 2006-2008). The % grassland is the most significant within this model, followed by the amount of seepage water and then the % other crops (arable land excluding maize land).

5.2 Model analysis

One way to gain further insight into the cause of the differences in the nitrate figures is to use the STONE model. However, to do so, one must first test the nitrate leaching that is calculated using STONE against the nitrate leaching measured at the LMM farms. The analysis of the nitrate leaching as calculated using the STONE model instrument is a two-step process.

The first step involves using the calculation results of all of the calculation units with the soil type marine clay and the presence of drain pipes located in the north-eastern marine clay area (Friesland and Groningen), north-western marine clay area (Noord-Holland), central marine clay area (Flevoland) and the south-western marine clay area (Zeeland, Zuid-Holland and Noord-Brabant) (figure 20).

Figure 20
Location of the calculation units of STONE with soil type marine clay and presence of drain pipes.

The calculated nitrate concentrations in drainage water were determined per marine clay area with respect to the three measuring seasons (October 2006 - March 2007; October 2007 - March 2008; October 2008 - March 2009). The simulated nitrate concentrations were determined by dividing – at ten-day intervals (this being the interval used in the model instrument STONE) - the nitrate load from the drain pipes by the simulated water flux from the drain pipes for the intervals at which a water flux is present. The nitrate concentrations calculated in this way were compared to the nitrate concentrations measured in the drainage water (figure 21) at the LMM farms.

The measured nitrate concentrations are shown as the average of the sampled farms in a region. The farm average corresponds to the region average in a fully representative random sampling of the farms in a particular marine clay area. That will not be the case in this random sampling. Particularly in the central marine clay area, due to the small number of farms that are sampled (4 – 6 farms), the chance of a farm deviating from the regional average may greatly influence the farm average.

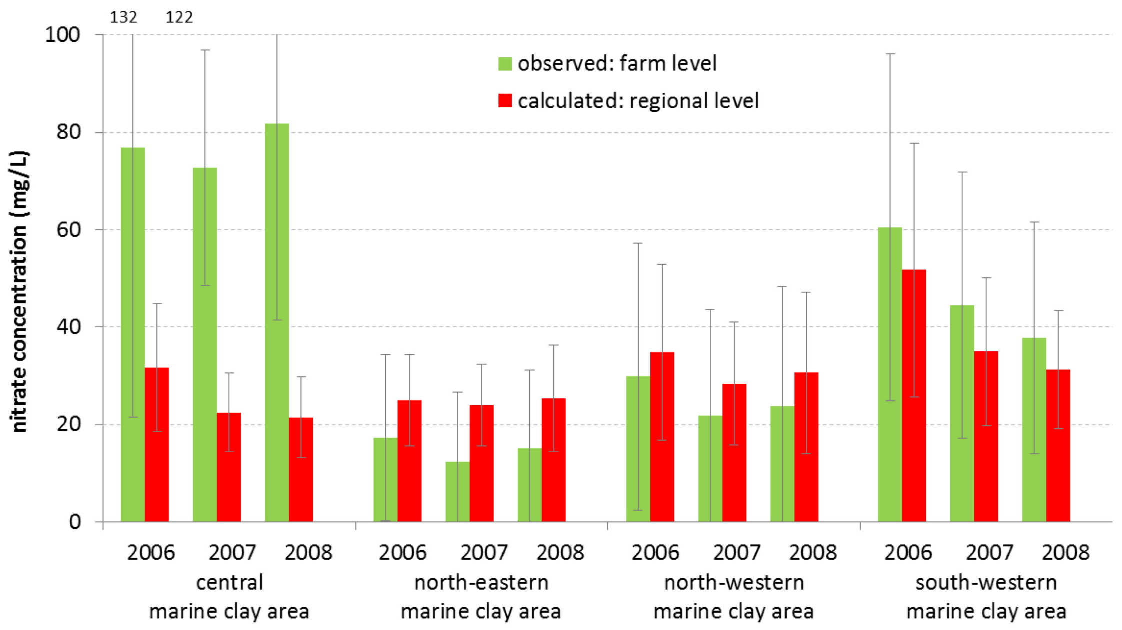


Figure 21
Measured and calculated nitrate concentrations in drainage water for the four marine clay areas and three years of calculation, including distribution.

Based on the comparison of the calculated and measured leaching of nitrate, it is evident that the measurements for the north-eastern, north-western and south-western marine clay areas can be adequately described using the model system (figure 21). The model overestimates the measurements for the north-eastern clay area, but the measured and calculated figures are within the limits of uncertainty. However, the model underestimates the nitrate concentrations for all three of the measuring seasons with respect to the central marine clay area.

Based on the model input, we then looked for an explanation for the differences in the nitrate concentrations in the drainage water. It is evident on the basis of the statistical analysis in paragraph 5.1.1 that the land use, among other things, may be an explicative factor for the measured nitrate concentrations.
With respect to the north-eastern, north-western and south-western marine clay areas, the proportion of arable land is the lowest in the north-eastern marine clay area (48%) and the highest in the south-western marine clay area (88%).
Based on these three marine clay areas, there is an obvious relationship between the proportion of arable land and the nitrate concentrations in the drain pipes (figure 22). The proportion of arable land in the central marine clay area (95%) is higher than that of the south-western marine clay area. Based on the regression line (figure 22), an average calculated nitrate concentration of 40 mg/L can be expected with a proportion of arable land of that size. However, it is evident from the calculations that the nitrate concentrations in the central marine clay area are lower (an average of 25 mg/L over the three seasons).

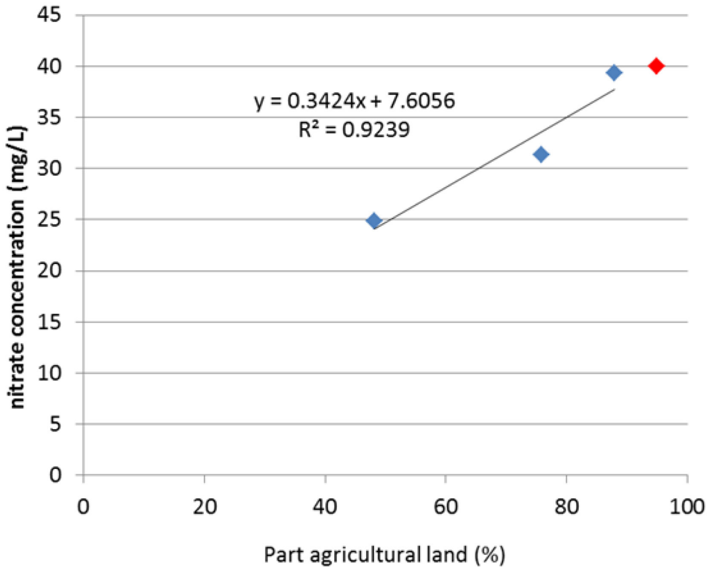


Figure 22
Relationship between the proportion of arable land and the nitrate concentration in the drain pipes for the north-eastern, north-western and south-western marine clay area for step 1 of the model analysis. The red dot is the expected nitrate concentration with respect to the proportion of arable land in the region of the central marine clay area.

In order to derive an explanation for the (too low) calculated nitrate concentrations in the central marine clay area, the model results for central were compared to the calculation results for the south-western marine clay area.

Based on the nitrate *loads* (see Annex 10), the leaching in the central marine clay area equals that of the south-western marine clay area, (both 23 kg/ha NO_3-N). However, the average water flux in the central marine clay area is higher (due to the higher seepage flux, among other things), resulting in lower nitrate concentrations (due to the effects of dilution).

The 'dilution effect' of the higher seepage flux in the central marine clay area does explain the lower nitrate concentrations compared to the south-western marine clay area, but not the difference between the calculated nitrate concentrations and the measured nitrate concentrations in the drainage water. Based on the calculated nitrate leaching (25 mg/L) for the central marine clay area, the difference compared to the measured nitrate concentrations is an average of more than 50 mg/L over the three measuring seasons (measured nitrate concentration of approx. 78 mg/L). The nitrate concentrations that can be expected on the basis of the percentage of arable land (40 mg/L) are also too low (slightly more than 35 mg/L).

One possible explanation is the fact that all of the marine clay areas in the entire region are considered in step 1, whereas only the average value on the farm level is used for the measurements. This deviation in scale may be the cause of the differences between the measured and calculated values.

Step 2 involved linking calculation units with the same characteristics on the basis of the characteristics of the farms on marine clay that can be found in one of the four regions. The selection is based on the following characteristics:

- Presence of drain pipes.
- Hydrology (groundwater level or groundwater class: wet, moderately dry, and dry).
- Soil type (PAWN soil unit).
- Land use (grassland, maize or arable land).

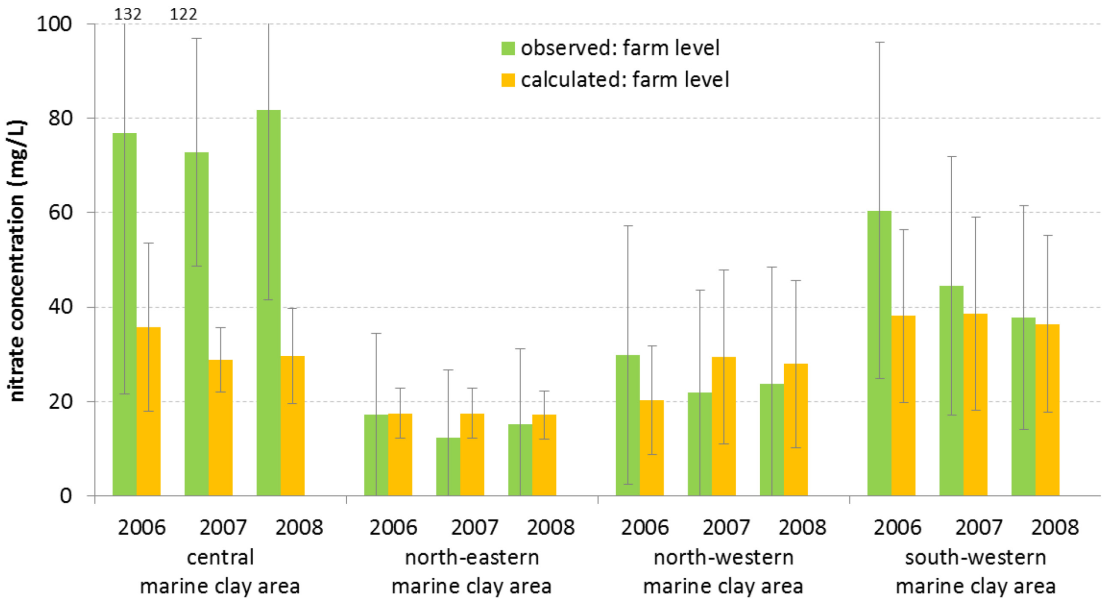


Figure 23
Measured and calculated nitrate concentrations in drainage water for the four marine clay areas and three measuring years.

Based on the calculated nitrate concentrations on a farm level, it is evident that, for most of the years concerned, the deviation with the measurements is smaller than that on the basis of the regional level (figure 23 and table 24). Only the south-western marine clay area shows an average deterioration (particularly for the year 2006). The deviation between measured nitrate concentrations and calculated nitrate concentrations for the central marine clay area also remains on the level of farm averages (Table 24). One can observe a smaller difference compared to the calculations on a regional level.

Table 24
Measured and calculated nitrate concentrations (mg/l) in drainage water for step 1 (region) and 2 (farm)for the marine clay areas.

Clay region/year	Measured (farm) (in mg/l)	Calculated (region) (in mg/l)	Deviation (positive= overestimate)	Calculated (farm) (in mg/l)	Deviation (positive= overestimate)
north-eastern					
2006	17.2	25.0	7.8 (45%)	17.5	0.3 (2%)
2007	12.4	23.9	11.5 (93%)	17.5	5.1 (41%)
2008	15.2	25.4	10.2 (67%)	17.2	2.0 (13%)
Average	*14.9*	*24.8*	*9.9 (66%)*	*17.4*	*2.5 (17%)*
north-western					
2006	29.8	34.8	5.0 (17%)	20.3	-9.5 (-32%)
2007	21.8	28.3	6.5 (30%)	29.4	7.6 (35%)
2008	23.7	30.6	6.9 (29%)	27.9	4.2 (18%)
Average	*25.1*	*31.3*	*6.2 (25%)*	*25.9*	*0.8 (3%)*
central					
2006	76.9	31.6	-45.3 (-59%)	35.8	-41.1 (-53%)
2007	72.7	22.4	-50.3 (-69%)	28.8	-43.9 (-60%)
2008	81.8	21.5	-60.3 (-74%)	29.6	-52.2 (-64%)
Average	*77.2*	*25.2*	*-52.0 (-67%)*	*31.4*	*-45.8 (-59%)*
south-western					
2006	60.4	51.7	-8.7 (-14%)	38.1	-22.3 (-37%)
2007	44.5	35.0	-9.5 (-21%)	38.5	-6.0 (-13%)
2008	37.7	31.3	-6.4 (-17%)	36.4	-1.3 (-3%)
Average	*47.5*	*39.3*	*-8.2 (-17%)*	*37.7*	*-9.8 (-21%)*

The relationship between the proportion of arable land and the calculated nitrate concentrations is also shown for step 2 (figure 24).

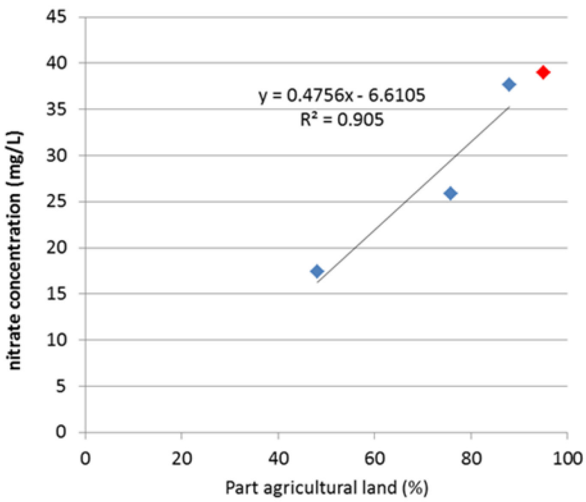


Figure 24
Relationship between the proportion of arable land and the nitrate concentration in the drain pipes for the north-eastern, north-western and south-western marine clay area for step 2 of the model analysis. The red dot is the expected nitrate concentration with respect to the proportion of arable land in the region of the central marine clay area.

Based on the percentage of arable land in the central marine clay area (95%), one can expect a nitrate concentration of 39 mg/L). And so it is evident from step 2 as well that the nitrate concentration observed at the LMM farms in the central marine clay area is higher than can be calculated/expected on the basis of model calculations or on the basis of the proportion of arable land.

Therefore the high nitrate concentration in the central marine clay area can only be partially explained by the high proportion of arable land and so there must be some other cause. It is known with respect to the central marine clay area (particularly the IJsselmeer Polders) that preferential flows exist due to the formation of cracks in the clay soils. These mainly concern maturation cracks that came about during the construction of these polders (see 3.1.2 'Physical properties of the soil'). The history of the development of shrinkage cracks and the effect on the leaching of nitrate is explained in more detail in Annex 1.
These preferential flows have not yet been implemented in the current STONE model instruments.

5.3 Discussion

It was examined in phase 2 whether there are relationships between the measured nitrate concentrations in the drainage water and the physical-environment factors on a farm level and the land use.
In an ideal situation, the data concerning the physical-environment factors of the LMM farms should be collected at the farms in combination with nitrate measurements. However, this is not feasible in view of the completion time of the project and the corresponding costs, which is why it was decided to determine the physical-environment factors of the LMM farms using the various data files (Table 25).

Table 25
Overview of the source files that were used to determine the physical-environment factors of the LMM farms.

Physical-environment factor	Sources
Pyrite contents	Pyrite map
Seepage flux	NHI-upward seepage map
Soil type	1:50.000 soil map
	PAWN soil map (deviation of the soil map)
Gt class	1:50.000 soil map
Amount of organic matter	Soil Information System
	1:50.000 Soil map

The scale that the various data files concern (national), is not (adequately) in keeping with the scale to which it is applied (farms). This means it is possible that the 'actual' physical-environment factors at the farms deviate from the attributed physical-environment factors. This is to be taken into account when interpreting the results of the regression analysis. In addition, one must take into account that there are doubts concerning the applicability of the LMM-measuring network where it concerns answering the knowledge questions because the LMM-network was set up for other purposes.

The number of participating farms in the central region is significantly smaller than that of the other regions. The extent this influences the results of the regression analysis and the model results is not yet clear. It is therefore quite possible that the average leaching of nitrate in the central region is greatly influenced by 'coincidental' peaks from one or more farms in this region.
It is evident from the model analysis that the simulated leaching of nitrate on a regional level shows the same trend, in broad outlines, as the measurements on a farm level within the region, but that a deviation is

observed between the simulated and the measured nitrate concentrations. This deviation between the measured and the calculated nitrate leaching decreases if the model analysis is conducted on a farm level. This demonstrates that the average leaching of nitrate of the participating farms deviates from the average leaching of nitrate of all of the farms on marine clay in the four marine clay areas studied.

6 Conclusions and recommendations

This study examined to what extend the higher nitrate concentrations in the central and south-western marine clay areas compared to the other marine clay areas can be explained by:

1) *a higher (average) nitrogen surplus of the soil balance or*
2) *soil and groundwater characteristics (clay content, seepage water, organic matter content, pyrite content, etc.), or*
3) *land use (emphasis on grassland or emphasis on arable land).*

It is evident from the results of a single regression analysis that, with respect to the years 2006-2008, no significant, positive relationship can be found between the measured nitrate concentrations in the drainage water and the nitrogen surplus of the soil balance on a farm level. If one conducts a multiple regression analysis, the differences between the LMM farms in terms of the nitrate concentrations can still not be explained by the nitrogen surplus of the soil balances.

On the basis of the multiple regression analysis it is clear that, depending upon the measuring year, 43% to 62% of the differences in the nitrate concentrations between the LMM farms can be significantly explained by differences in land use (% grassland and % other crops) and the amount of seepage water. The percentage of grassland is most significant, followed by the amount of seepage water. The least significant of the three variables is the percentage of other land use (arable land excluding maize).

In addition to the 'best' model, there are also statistical relationships in which the variables *soil type* and *groundwater table* are significant for all of the years examined in the study. The explained variance for the differences in the measured nitrate concentrations are however lower. The variables *nitrogen surplus of the soil balance, organic matter content of the soil* and the *pyrite content* in the layer between 1.0 and 1.2 meters are not found to be significant in any statistical relationship for the years concerned. If the years were examined separately, a variable can be significant for that particular year.

Model-based analysis
In order to establish whether certain processes in the soil (mineralisation, etc.) may play a role in explaining the differences in the nitrate concentrations, the results of the process-oriented nutrient emission model STONE was used.

The STONE model is valid in describing the measured nitrate concentrations in the north-eastern, north-western and south-western marine clay areas. Concerning the central marine clay area, however, the nitrate concentrations are underestimated for the three measuring seasons.
The underestimating of the nitrate concentrations may be explained by the high amount of seepage water in the (available) model application (dilution effect). In addition the presence of cracked soils in the central marine clay area (particularly the IJsselmeer Polders) may lead to the occurrence of preferential flows which may have resulted in higher nitrate concentrations in practice.
Crack soils have not (yet) been implemented in the current STONE model, as a result of which the calculated nitrate concentrations are lower than the measured concentrations.

Follow-up research
The STONE-model application can help to get a better understanding of the measured nitrate concentrations because much more processes are taken into account which cannot be used (on forehand) in statistical

analysis (mineralisation, denitrification etc.). However it is recommended to incorporate the influence of cracked soils into the model before such evaluations are made, because cracked soils occur in the Central clay area and can cause additional losses of nutrients. Subsequently scenario analysis can be performed to determine the effectiveness of mitigation options. Possible mitigation options are for example fertilisation strategies in combination with a certain type of land use and hydrological measures (e.g. control drain pipes, holding water to increase the denitrification capacity).

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Annex 1: Crack formation

The reason why networks of large ripening cracks occur in the IJsselmeer polders but not in other clay areas is probably tied in with the history of how the clay soils in the IJsselmeer polders formed. Following the reclamation and drainage of the IJsselmeer Polders, submarine sedimentation left the silt bed with a very low density and a high content of water and organic matter (including peat deposits). As a result of this, after further drainage, large shrinkage cracks formed which appeared to be very stable (Van den Akker et al., 2011). However, these cracks are gradually shrinking further under the influence of, amongst other factors, the loss of organic matter due to erosion. Nowadays the movement of heavy machinery is probably a major cause of the acceleration in the shrinkage of the cracks (oral comment by Jan van den Akker), which is reflected in, for example, the need for smaller drain intervals. In other words, the porosity of the soil is no longer as high as before. Ripening and shrinkage cracks appear in many clay soils in the Netherlands (Tiktak et al., 2010). However, it is plausible that, with the passage of time, extreme cracks like those in the IJsselmeer polders have largely disappeared.

Crack-shaped macropores in clay soils substantially assist the drainage of surplus water. The saturated porosity of the soil matrix of medium-textured to coarse-textured clay soils is very low in terms of millimetres, working out at one centimetre a day at the most. Networks of cracks that run to the ditch walls or to the depth of the drains play a key role in ensuring that this clay soil can be adequately drained, usually with pipes.

In wet periods most shrinkage cracks swell and close when the matrix is saturated. Hairline cracks usually remain, which make continued drainage possible. This requires drain intervals of around 10-20 metres. However, the ripening cracks in the IJsselmeer polders are permanent cracks with a porosity of 300-500 m per day, which is inordinately high and explains why drain intervals are sometimes very long, even up to 48 metres (Groen, 1997). This means that surplus precipitation containing dissolved substances can be effectively drained to the ditch.

These substances must, of course, enter the water first. In the case of macropores – cracks but also root and earthworm tunnels – which run from ground level to the drainage pipes, there is an obstruction between the surface and the drains. Because of this, water will flow across the surface to the macropores, especially if the infiltration capacity of the soil matrix is overstressed. During that process, substances must be absorbed by the water in order to end up in the macropores. The uppermost centimetres can also become saturated and water can absorb substances via that layer and flow to the macropores.

Substances sensitive to this form of transport, such as recently spread manure or pesticides, lie at surface level or are concentrated in the uppermost centimetres of the soil profile (e.g. Hendriks et al., 1997; Hendriks et al., 1999; Larsson, 1998; Smelt et al., 2003; Tiktak et al., 2012). Once substances have been largely absorbed in the deeper soil through transportation via the matrix along with downward percolating rainwater, they are more or less shielded from fast transportation via macropores. Flowing rainwater on the surface cannot absorb substances and this results in the bypass of 'clean' water.

Forms of nitrogen are particularly susceptible to this mechanism. Smelt et al. (2003), performed a study on drained, macroporous medium-textured clay in Andelst (Gelderland) and found indications of this process in the case of nitrate, and strong indications for preferential transportation via macropores in the case of phosphate and pesticides. Larsson (1998) also found that, in the case of nitrate leaching, macropores can lead to bypass of rainwater with low concentrations, rather than evidence of preferential transportation of nitrate. The cause of this variation in the behaviour of substances in relation to preferential water transportation via macropores that run from ground level to drain probably lies in the degree to which they bind with the soil matrix. Substances that bind strongly are available in the topsoil for longer periods for transportation by rainwater flowing to macropores.

The situation in the IJsselmeer polders is fundamentally different: the uppermost 35 cm is ploughed, which means that the former structure of the ripening crack network has disappeared entirely (Groen, 1997). This top layer often consists of light to coarse *loam* (sandy and silty clay) which displays some degree of cracking, but with relatively small aggregates and clods (oral explanation from Jan van den Akker). Moreover, a low-porosity furrow could occur at a depth of 35-40 cm and cause the accumulation of water deep in the topsoil (Groen, 1997). Consequently, the water that has percolated down from the top layer has considerable contact with the soil, which can lead to a vigorous exchange of substances between soil and water. Because of this, Groen (1997) was able to simulate the leaching accurately with a bromide tracer applied at ground level for clay soil in the IJsselmeer polders with the aid of a model that simulated the transportation through the topmost layer with a classic CDE (Convection Dispersion Equation) approach, and the fast transportation via the ripening cracks with a notional drain just below the topmost layer with an interval of 0.3 metres and hence very low resistance.

When the bromide concept is transposed for nitrate, the following picture emerges: the top layer containing nitrate from manure and organic matter is adequately drained by the network of ripening cracks and is therefore well aerated. As a result, the oxygen-requiring processes of nitrogen mineralisation and nitrification can convert nitrogen combinations into nitrate to a reasonably optimal degree. Because of the strong interaction between the two, downward percolating water can take up nitrate from the soil. The nitrate-rich water percolates very quickly through the network of cracks to the drains and has relatively little contact with the soil because of the large volume of cracks. Conversion from nitrate through denitrification can therefore occur only to a very limited extent. In this way, it is possible that high concentrations of nitrate leach via the drains in the parts of the IJsselmeer polders where ripening cracks (still) occur.

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Annex 2: Composition of clay minerals in marine clay areas

Introduction
Publications were sought on the clay mineralogy in marine clay areas from a body of literature that was selected for a review of the geochemistry of the Dutch subsoil and with the aid of new searches in Google and in Omega (search programme of Utrecht University library). Articles were found on the origins and mineralogical composition of the silt deposits in tidal marshes in Zeeland and the Wadden Sea region (Favejee, 1951, incorporated in Table 25) and the marine clay in Friesland/Groningen, West Friesland and Zeeland (Breeuwsma, 1985, incorporated in Table 26).

Clay mineralogy
It is assumed on the basis of the limited body of available literature that the marine clay areas (Friesland/Groningen and Zeeland) have the same origin and composition as the clay in the tidal marshes of Zeeland and the Wadden Sea region (Favejee, 1951). Breeuwsma (1985) shows the composition of the marine clay in Friesland and Groningen in the table but not in West Friesland or Zeeland. His report refers continually to the differences between marine clay and fluvial and brook clay, and suggests that, in contrast with fluvial and brook clay, the composition of the marine clay from analysed areas (Friesland/Groningen, West Friesland and Zeeland) has a uniform composition.

Table 26 (Breeuwsma, 1985) shows a compilation of a number of studies of fluvial and marine clay, which looked not only at the clay minerals but also at the concentration of the 'free oxides' (SiO2, Al2O3 and Fe2O3), quartz and feldspars. The clay minerals in the lutum fraction were determined on the basis of four x-ray diffraction curves (air-dry, treated with glycerine and heated to 350 and 450^{o} C). This also allowed the presence of mixed-layer minerals (such as smectite-illite, illite-chlorite, etc.) to be detected. Fifty-five marine clay samples from Friesland/Groningen, West Friesland and Zeeland were examined. In contrast with the findings of Favejee (1951), smectite and chlorite were also found in the marine clay. This is because Favejee's original protocol (1951) was extended by Beeuwsma (1985), who added three other measurements (besides air-dry, treated with glycerine and heated to 350 and 450^{o}C). Breeuwsma's report (1985) refers continually to the differences between marine clay and fluvial clay, which suggests that the marine clay has a uniform composition in contrast with fluvial and brook clay.

The results for the free oxides point to strong similarities between the marine clay from Friesland/Groningen, West Friesland and Zeeland and to clear differences from the fluvial and brook clay. The free iron in marine clay is clearly lower and the silicate concentration higher (Table 26). The saltwater clays from tidal sedimentation in the fraction smaller than 2μm, and especially, the fraction smaller than 0.4μm show a far higher iron content than the freshwater clays from tidal sedimentation (Table 27).

Origin and composition of marine sediment and sand
The origin of the sediment was ascertained by studying the < 0.5 μm, 0.5-2 μm and 2-10 μm fractions with XRD analyses by Favejee (1951) and the 10-40 μm fractions with microscopic recognition (Crommelin, 1943). In addition, the origin of the sand from the Wadden Sea region was investigated using Edelman's heavy mineral method (Baak, 1936 and Crommelin, 1940).
The findings of these studies were all the same: the sand and the sediment have a marine origin and were brought in from the North Sea via the tidal inlets in the Wadden Sea and not via the Ems, Weser, Elbe or the

Rhine rivers. Van Straaten (1954) indicates that the same applies to the sand in the estuaries of Holland and Zeeland. The sediment along the Dutch coast therefore has a uniform composition.

The mineralogical composition of the sediment from the North Sea, the Wadden Sea and the estuaries of Zeeland is shown in Table 25 (Favejee, 1951). The largest part of the < 0.5μm and the 0.5-2 μm fractions consists of illite and quartz while the 2-10 μm fraction consists mainly of quartz. The amount of quartz decreases with the size of the grain, while the amount of illite increases. The remainder consists of kaolinite, montmorillonite, carbonates, muscovite, feldspar, iron components and organic matter. No clear distinction can be drawn between the sediment from the Wadden Sea, the Eastern and Western Scheldt, the bed of the North Sea and the suspended particulate matter from tidal inlets. Table 25 does, however, show that there is a clear difference between marine and fluvial sediment. The fluvial sediment has lower concentrations of montmorillonite and strongly fluctuating percentages of kaolinite and quartz.

Conclusion

On the basis of the limited literature, we must assume that there are no differences between the mineralogical composition of the marine clay in Friesland/Groningen, West Friesland (North Holland) and Zeeland.

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Table 26
Mineralogical composition of the fractions < 0.5 µm, 0.5-2 µm and 2-10 µm from different types of sediment (Favejee, 1951).

I : recent Wadden sediment from land reclamation along the coast of Groningen
II : sediment from sea water in the tidal inlets of the Wadden Sea
III : samples from the bed of the North Sea, south and south-east of Dogger Bank and in the German Bight
IV : sediment from rivers, a) Ems, b) Weser, c) Elbe, d) Rhine
V : old clay banks in the Wadden Sea
VI : sediment from the Wadden Sea, a) mussel banks, b) sediment with shell fragments, c) mussel pellets
VII: sediment from the neap tide, south of Schiermonnikoog
VIII: sediment from tidal marshes in Zeeland

		Fraction < 0.5µm				Fraction 0.5-2µm				Fraction 2-10µm				
Origin sediment		illite	kaol.	montm.	quartz	Illite + musc.	kaol.	montm.	quarts	illite + musc.	kaol.	montm.	quarts	feldspar
Wadden Sea	I	± 80	5-10	± 10	± 4	50-60	5-10	5-10	± 30					
Wadden Sea	VIa	80-90	5-10	± 5	± 4									
Wadden Sea	VIb	80-90	± 5	5-10	2-4	50-60	± 10	5-10	25-30	± 30	± 5	± 5	50-60	± 5
Wadden Sea	VIc	80-90	± 5	3-5	± 6	± 60	± 5	± 5	± 30					
Wadden Sea	VII	± 80	5-10	5-10	± 6	± 60	5-10	± 5	± 30					
Wadden Sea	V	± 80	5-10	5-10	± 4	± 60	5-10	± 5	± 25	± 60	5-10	± 5	± 50	5-10
Wadden Sea	II	80-90	5-10	± 5	4-6	± 60	5-10	± 5	± 30	20-30	± 5	± 5	± 60	5-10
North Sea	III	80-90	5-10	3-5	± 2	± 50	± 15	5-10	± 30	± 20	± 10	± 5	± 50	± 10
Zeeland	VIII	80-90	± 5	5-10	2-4	± 60	± 10	5-10	± 25					
Fluvial clay	IVa	> 95	-	< 3	< 1	> 90	< 1	< 3	> 50	> 50	< 1	< 3	> 90	< 1
Fluvial clay	IVb	± 90	3-5	< 3	± 5	± 60	± 5	± 5	30-40	± 30	3-5	< 3	± 60	± 5
Fluvial clay	IVc	70-80	5-10	< 3	± 15									
Fluvial clay	IVd	80-90	± 10	< 3	± 5	40-50	± 10	± 5	± 40					

Table 27
Mineralogical composition in (percentage weight) of the lutum fractions for the most important Holocene clay deposits in the Netherlands, after removal of humus, carbonates and sulphides (Breeuwsma, 1985).

Deposit	Clay minerals					"Free" Oxides[3]			Quartz	Feldspar
	Kaolinite[2]	Illite[1]	Vermiculite[1]	Smectite[1]	Chlorite[1]	SiO_2	Al_2O_3	Fe_2O_3		
Fluvial clay										
Rhine flood plains	5-10	35-40	10-20	10-15	5-10	3.43	1.44	4.30	5-10	<5
Rhine sub-Atlantic	5-10	30-40	10-20	15-20	<5	4.69	2.24	3.32	5-10	<5
Rhine-subboreal	5-10	30-35	5-10	30-35	<5	4.76	1.84	3.48	5-10	<5
Maas/Meuse	5-10	30-35	5-10	30-35	<5	3.88	1.66	3.89	5-10	<5
'Brook clay, east Netherlands'	5-10	<10	<5	50-80	0-20[4]	5-20	2.45	3.40	5-10	<5
Marine Clay										
Freshwater tidal deposits	5-10	35-40	10-20	10-15	5-10	2.57	1.33	3.25	5-10	<5
Saltwater tidal deposits						4.61	1.07	3.06	5-10	<5
Friesland/Groningen	5-10	30-40	<5	30-40	<5	7.12	1.16	2.52	5-10	<5
West Friesland						7.39	0.62	2.16	5-10	<5
Zeeland						5.52	1.03	2.81	5-10	<5

1) Estimate relates to the total number of layers in clay minerals. Smectite and vermiculite occur only as components of mixed-layer minerals with illite. This also applies to chlorite to some extent.
2) Determined chemically after boiling with 0.5 N lye.
3) Determined chemically. For SiO_2 and A_2O_3 after boiling with N lye, for Fe_2O_3 after treatment with a dithionite-citrate-bicarbonate mixture.
4) Secondary chlorite.

Table 28
Chemical composition (in weight percentages) of two representative samples from saltwater and freshwater clay from tidal deposits (Breeuwsma, 1985). X: iron removed in bulk monster; XX: including FeO.

Element	Fraction < 2μm[X]		Fraction <0.4μm[X]	
	W23 saltwater	W30 freshwater	W23 saltwater	W30 freshwater
SiO_2	47.3	46.4	53.2	52.8
Al_2O_3	19.7	23.0	19.6	21.9
Fe_2O_3	7.10	4.34	12.0	7.54
FeO	0.55	0.84	Not determined	Not determined
MgO	3.32	3.69	4.57	4.53
K_2O	3.22	3.52	2.21	2.72

Annex 3: Soil types

Split into six categories: 1 (sand), 2 ('moer' podzol and enk earth soil), 3(peat and 'drecht' entisol), 4 (marine clay), 5 (clay knik) and 6 (cluster)

Table 29
Soil types with codes and descriptions according to the soil map 1:50.000, clustered according to the different categories.

Soil Type	Code	Description	Number	Category
cHn	cHn	'laar' podzol	1	1
gMn	gMn	knippig, polder entisol	13	5
Hn	Hn	'veld' podzol		1
hV	hV	'voop' peat		3
kV	kV	'vaard' peat	1	3
Mn	Mn	polder entisol	37	4
Mv	Mv	'drecht' entisol	4	3
pV	pV	'weide' peat		3
pZn	pZn	'goor' earth soil		1
zEZ	zEZ	black enk-earth soil	1	2
Zn	Zn	'vlak' entisol	3	1
zWp	zWp	'moer' podzol		2
kMn	kMn	knik soil, polder entisol	9	5
Mo	Mo	non-ripened sedimentary entisol		4
pMn	pMn	marine clay, 'leek/woud' earth soil	5	4
kWz	kWz	'moer' earth soil sand- or clay-covered	1	4
U15T	Mn	polder entisol	1	6
Sn	Sn	'vlak' entisol		1
U370				6
U5354	Mn			6
U0708			2	6
Wo	Wo	unripened sandy or clay, 'plas' earth soil	2	4
U4849	Mn		1	6
U1419				6
U37W	Zd			6
U09T				6
pMo	pMo	unripened, 'tocht' earth soil		4
U2425			1	6
U4248	Aem	equalised marine clay soil with local peat		6
Aep	Aep	equalised and incorporated marine clay soil, ripened	2	4
U1318	Hn		1	6
U2021				6
vWp	vWp	'moer' podzol		2
U1920	pMo	unripened	1	6
U07W	Mo	unripened		6
U43W	nMo	unripened		6
AZW	AZW	Marine clay soil Wieringermeer		6

Annex 4: Used datasets with depths

Table 30
Datasets used and maximum depth of the data for each top geographical area

Top geographical area	Dataset(s) used	Depth
1a (Zeeland)	data Gunnink + dataset Van der Veer (2006) + dataset Bakker et al. (2007)	to 51 m. below gl
1b (Holland)	data Van Gaans et al. (2007)	to 37 m. below gl
1c (dunes)	5 shallow samples from dataset Van der Veer (2006)	to 1.1 m. below gl
1d (Zeeland)	data Gunnink (3 drillings) + one shallow sample from dataset Van der Veer (2006)	to 30 m. below gl
2a	data Van Gaans et al. (2007)	to 37 m. below gl
2b/3a/3b	data test depth nitrate (mid-Netherlands)*	to 8 m. below gl
2c	data Van der Veer (2006)	to 1.1 m. below gl
3c	data Van der Veer (2006)	to 1.1 m. below gl
4a1, 4a1, 4b, 4c, 4d1, 4d2	data Bakker et al. (2007), Klein and Griffioen (2008)	< 50 m below gl
4a2, 4d2	data Van der Veer (2006)	to 1.1 m. below gl
5a1, 5a2, 5b1, 5b2, 5c1, 5c2	data Klein and Griffioen (2010)	to 36 m. below gl
6a, 6b	data test depth nitrate (mid-Netherlands)*	to 8 m below gl
7a, 7b	Not taken into consideration (loess chalky area)	-

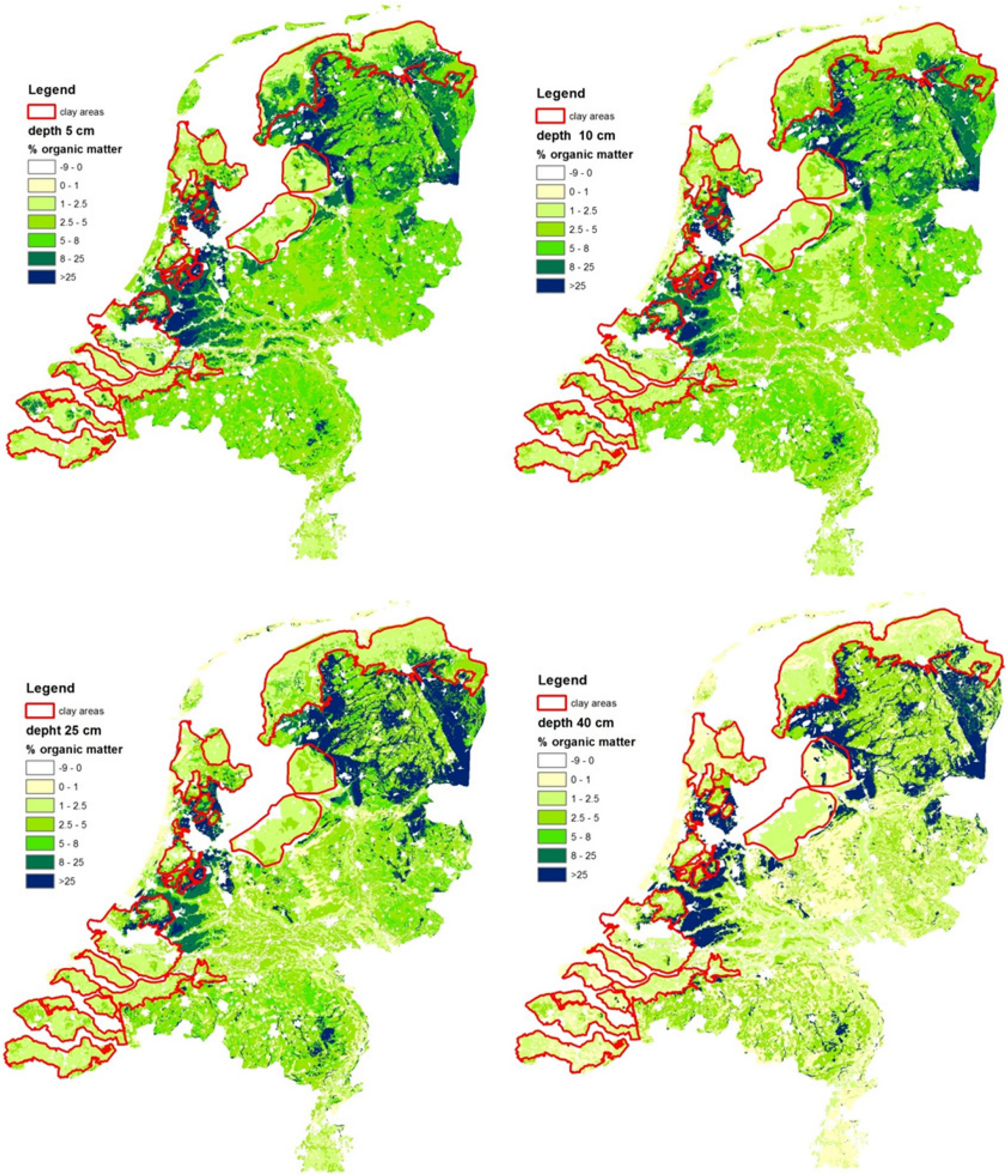
* New drillings were installed for the testing depth of nitrate (Groenendijk et al., 2008) in the east and middle of the Netherlands and the samples were analysed. These data were used.

Annex 5: Pyrite concentrations non-relevant top systems

Table 31
Number of used samples and their average pyrite concentrations for a depth of 1-2 metres below ground level.

Top system	**Number of samples**			**Average**		
	Clay/Loam	Peat	Sand	Clay/Loam	Peat	Sand
1a, 1d, 4d2	15	2	6	0.41	1.88	0.27
1b	14	11	8	1.26	4.95	0.40
1c	1	-	4	0.04	-	0.04
2a	67	29	27	0.55	1.61	0.22
2b	1	1	18	0.09	`0.45	0.09
2c, 3c	45	34	11	0.98	2.64	0.21
3a	-	-	7	-	-	0.09
3b	-	-	10	-	-	0.09
4a1	2	-	11	0.42	-	0.09
4a2	3	-	8	0.04	-	0.06
4b	12	8	36	0.11	1.37	0.06
4c	-	-	6	-	-	0.04
4d1	24	-	55	0.05	-	0.06
5a1	25	-	33	0.09	-	0.09
5a2, 5b2	39	9	19	0.40	2.64	0.82
5b1	-	4	4	-	1.90	0.12
5c1	5	-	13	0.09	-	0.09
5c2	7	10	9	0.09	4.70	0.09
5c3	1	-	14	0.04	-	0.09
6a	-	-	12	-	-	0,09
6b	1	-	8	0.09	-	0.10

Annex 6: Organic substances (%) for the different layers



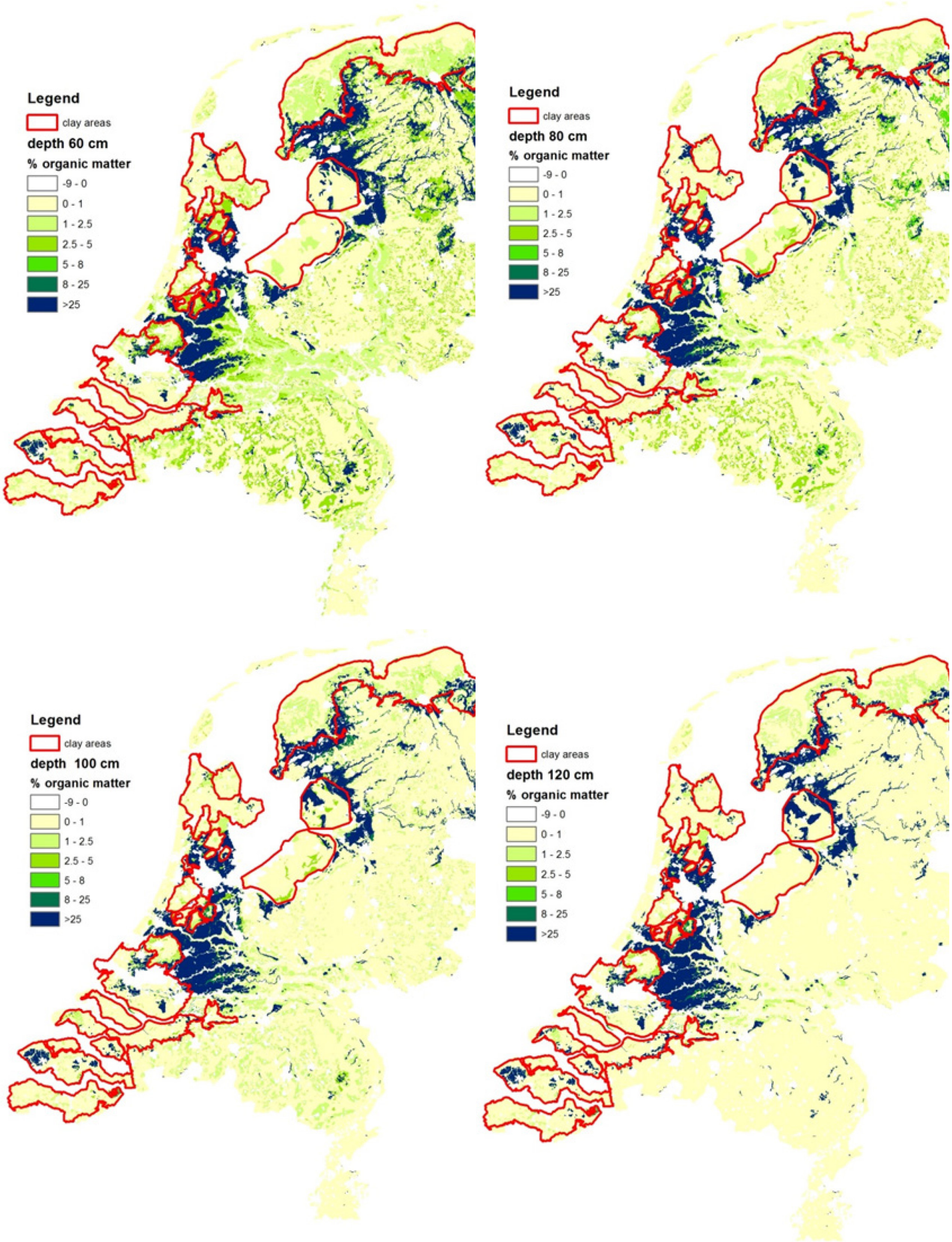


Figure 25
Organic substances (%) for layers 5, 10, 25, 40, 60, 80, 100 and 120 cm below ground level in the Netherlands.

Annex 7: Histogram: nitrate concentrations and nitrogen surplus of the soil balance

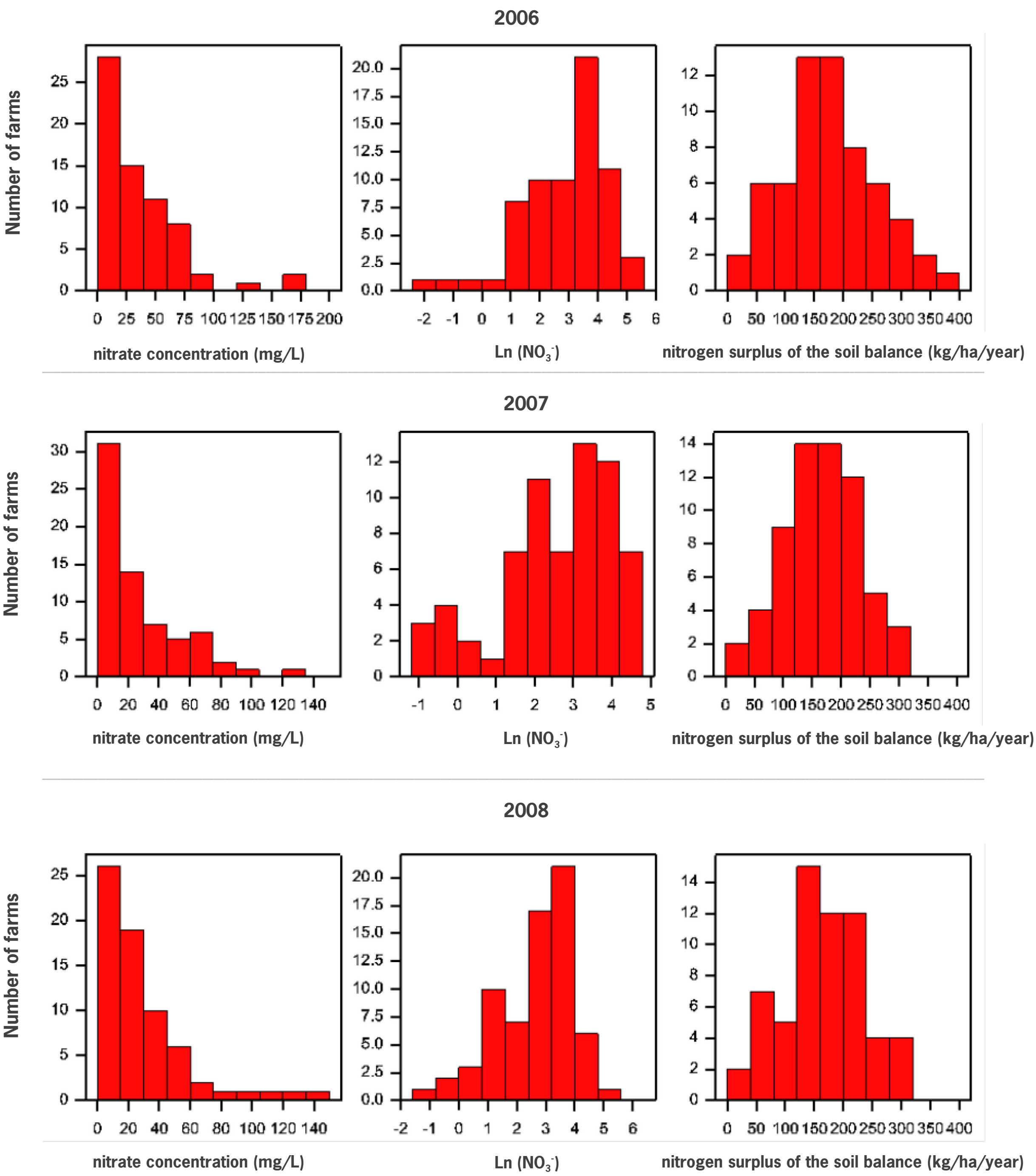


Figure 26

Histograms showing the NO3 concentration on the original scale and the log scale, and histograms of the nitrogen soil surplus H10 for 2006, 2007 and 2008 separately.

Annex 8: Groundwater scale categories for LMM farms

Table 32
Groundwater Scale categories for LMM farms based on the 1:50,000 soil map and the database of the National Institute for Public Health and the Environment (RIVM).

	1:50,000 soil map	I	II	II*	III	III*	IV	V	V*	VI	VII	VIII	VIII*
	Unknown	Wet					Medium				Dry		
RIVM database													
I		-	-	-	-	-							
II		-	9	-	3	-							
II*		-	-	-	-	-							
III		-	3	-	6	-							
III*		-	-	-	-	-				2			
IV							5	-	-	-			
V	5				6		-	54	-	-			
V*					3		-	3	29	3			
VI	1						-	-	2	64			
VII							3			1	-	-	-
VII*											-	-	-
VIII											-	-	-
Total	6		12		18		8	57	31	71			

Table 33
Number of LMM farms in the 'wet', 'medium' and 'dry' clusters.

	Wet	Medium	Dry	Unknown
Wet	21	2	-	-
Medium	9	160	-	6
Dry	-	4	-	-

It may be concluded from the table that the dominant category in the groundwater scale corresponds exactly for both methods in the case of 167 farms (82%). Setting aside the GS category, and looking only at the clusters (dry, medium, wet), 89% of the farms correspond. Differences were ascertained for 21 farms, six of which have an unknown GS categorisation (on the basis of the overlay). Ultimately the distribution from the RIVM database was used for the analysis.

Annex 9: Results of the statistical analyses

Results: 'All possible subset selections' for different factors in 2006

Best subsets with 1 term

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
45.22	15.62	3	.000	-	-	-	-	-	-	-	-
25.09	40.10	3	-	-	-	-	.000	-	-	-	-
21.27	45.21	5	-	-	-	.002	-	-	-	-	-
20.78	45.13	2	-	-	.000	-	-	-	-	-	-
15.91	51.27	3	-	.003	-	-	-	-	-	-	-
8.01	60.95	2	-	-	-	-	-	-	.019	-	-
<0.00	72.92	2	-	-	-	-	-	-	-	.766	-
<0.00	73.12	2	-	-	-	-	-	-	-	-	.967

Best subsets with 2 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
53.27	9.63	7	.000	-	-	.017	-	-	-	-	-
53.09	7.94	5	.000	.007	-	-	-	-	-	-	-
52.31	7.92	4	.000	-	.004	-	-	-	-	-	-
48.18	13.69	5	.000	-	-	-	.089	-	-	-	-
44.49	17.26	4	.000	-	-	-	-	-	-	.594	-
44.47	17.29	4	.000	-	-	-	-	-	.610	-	-
44.29	17.50	4	.000	-	-	-	-	.760	-	-	-
44.25	17.55	4	.000	-	-	-	-	-	-	-	.817

Best subsets with 3 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
58.72	4.56	8	.000	-	.008	.025	-	-	-	-	-
57.66	6.78	9	.000	-	-	.008	.035	-	-	-	-
57.33	7.13	9	.000	.042	-	.073	-	-	-	-	-
53.11	10.75	8	.000	-	-	.015	-	-	-	.367	-
52.66	11.24	8	.000	-	-	.017	-	-	-	-	.549
52.63	9.41	6	.000	.316	.482	-	-	-	-	-	-
52.34	9.74	6	.000	.007	-	-	-	.667	-	-	-
52.34	11.59	8	.000	-	-	.021	-	-	.861	-	-

Best subsets with 4 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
59.88	5.47	10	.000	-	.062	.013	.191	-	-	-	-
58.74	5.60	9	.000	-	.005	.021	-	.315	-	-	-
58.72	5.63	9	.000	-	.005	.019	-	-	.321	-	-
58.21	8.30	11	.000	.278	-	.039	.233	-	-	-	-
57.92	6.49	9	.000	-	.013	.027	-	-	-	.781	-
57.88	6.54	9	.000	-	.011	.037	-	-	-	-	.877
57.43	8.07	10	.000	-	-	.007	.039	-	-	.394	-
57.16	8.35	10	.000	.030	-	.060	-	.373	-	-	-

Results: 'All possible subset selections' for the different factors in 2007

Best subsets with 1 term

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
43.18	26.38	3	.000	-	-	-	-	-	-	-	-
31.04	43.67	2	-	-	.000	-	-	-	-	-	-
21.04	58.48	3	-	-	-	-	.000	-	-	-	-
17.94	62.97	3	-	.001	-	-	-	-	-	-	-
17.14	64.06	5	-	-	-	.005	-	-	-	-	-
6.39	80.01	2	-	-	-	-	-	-	.027	-	-
0.31	88.97	2	-	-	-	-	-	-	-	-	.279
<0.00	90.51	2	-	-	-	-	-	-	-	.457	-

Best subsets with 2 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
59.31	3.99	4	.000	-	.000	-	-	-	-	-	-
52.34	14.76	5	.000	.002	-	-	-	-	-	-	-
46.96	23.69	7	.000	-	-	.100	-	-	-	-	-
44.73	24.13	3	-	-	.000	-	-	-	.000	-	-
43.77	26.14	4	.000	-	-	-	-	-	-	.208	-
43.18	27.59	5	.000	-	-	-	.374	-	-	-	-
43.09	27.11	4	.000	-	-	-	-	-	-	-	.344
42.86	27.43	4	.000	-	-	-	-	-	.414	-	-

Best subsets with 3 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
60.92	3.78	6	.000	.121	.001	-	-	-	-	-	-
60.05	7.01	8	.000	-	.000	.294	-	-	-	-	-
59.57	4.62	5	.000	-	.000	-	-	.245	-	-	-
58.79	5.72	5	.000	-	.000	-	-	-	.603	-	-
58.76	5.76	5	.000	-	.000	-	-	-	-	.634	-
58.62	5.95	5	.000	-	.000	-	-	-	-	-	.845
58.12	7.63	6	.000	-	.000	-	.838	-	-	-	-
53.49	16.58	9	.000	.012	-	.263	-	-	-	-	-

Best subsets with 4 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
62.09	6.44	10	.000	.096	.001	.236	-	-	-	-	-
60.44	6.49	8	.000	.080	.000	-	.521	-	-	-	-
60.38	5.54	7	.000	.124	.001	-	-	-	-	.628	-
60.36	5.58	7	.000	.129	.001	-	-	-	.653	-	-
60.36	5.58	7	.000	.219	.001	-	-	.653	-	-	-
60.29	5.67	7	.000	.121	.001	-	-	-	-	-	.739
59.84	8.30	9	.000	-	.000	.369	-	.400	-	-	-
59.75	8.41	9	.000	-	.000	.263	-	-	-	.440	-

Results: 'All possible subset selections' for different factors in 2008

Best subsets with 1 term

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
43.18	26.38	3	.000	-	-	-	-	-	-	-	-
31.04	43.67	2	-	-	.000	-	-	-	-	-	-
21.04	58.48	3	-	-	-	-	.000	-	-	-	-
17.94	62.97	3	-	.001	-	-	-	-	-	-	-
17.14	64.06	5	-	-	-	.005	-	-	-	-	-
6.39	80.01	2	-	-	-	-	-	-	.027	-	-
0.31	88.97	2	-	-	-	-	-	-	-	-	.279
<0.00	90.51	2	-	-	-	-	-	-	-	.457	-

Best subsets with 2 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
59.31	3.99	4	.000	-	.000	-	-	-	-	-	-
52.34	14.76	5	.000	.002	-	-	-	-	-	-	-
46.96	23.69	7	.000	-	-	.100	-	-	-	-	-
44.73	24.13	3	-	-	.000	-	-	-	.000	-	-
43.77	26.14	4	.000	-	-	-	-	-	-	.208	-
43.18	27.59	5	.000	-	-	-	.374	-	-	-	-
43.09	27.11	4	.000	-	-	-	-	-	-	-	.344
42.86	27.43	4	.000	-	-	-	-	-	.414	-	-

Best subsets with 3 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
60.92	3.78	6	.000	.121	.001	-	-	-	-	-	-
60.05	7.01	8	.000	-	.000	.294	-	-	-	-	-
59.57	4.62	5	.000	-	.000	-	-	.245	-	-	-
58.79	5.72	5	.000	-	.000	-	-	-	.603	-	-
58.76	5.76	5	.000	-	.000	-	-	-	-	.634	-
58.62	5.95	5	.000	-	.000	-	-	-	-	-	.845
58.12	7.63	6	.000	-	.000	-	.838	-	-	-	-
53.49	16.58	9	.000	.012	-	.263	-	-	-	-	-

Best subsets with 4 terms

Adjusted	Cp	Df	Regio	Land1	Land2	nPAWN	fgw3	H10	kwel	lnos	lnpyr
62.09	6.44	10	.000	.096	.001	.236	-	-	-	-	-
60.44	6.49	8	.000	.080	.000	-	.521	-	-	-	-
60.38	5.54	7	.000	.124	.001	-	-	-	-	.628	-
60.36	5.58	7	.000	.129	.001	-	-	-	.653	-	-
60.36	5.58	7	.000	.219	.001	-	-	.653	-	-	-
60.29	5.67	7	.000	.121	.001	-	-	-	-	-	.739
59.84	8.30	9	.000	-	.000	.369	-	.400	-	-	-
59.75	8.41	9	.000	-	.000	.263	-	-	-	.440	-

Annex 10: Nitrogen balances

North-east marine clay area

INPUT (kg.ha^{-1} N)	Org-N	NH4-N	NO3-N	OUTPUT (kg.ha^{-1} N)	Org-N	NH4-N	NO3-N
Atm. Deposition		11	6	Crop absorption		233	147
manure and chemical fertilisers	75	157	67	Gross mineralisation	285		
Crop remains	154			Nitrification		180	
Incorporation	40			Denitrification			85
Net mineralisation		245		Ground level run-off	0	0	0
Nitrification			180	Discharge to:			
				- 5th level	0	0	1
Infiltration from:				- drainage pipes	1	0	12
- 3rd level	0	0	0	- 3rd level	0	0	0
- 2nd level	0	0	0	- 2nd level	0	0	1
- 1st level	0	0	0	- 1st level	0	0	0
Upward seepage	0	1	0	Downward seepage	0	0	0
Total INPUT	**268**	**414**	**253**	**Total OUTPUT**	**287**	**414**	**249**
Supply change fixed component / complex					0	0	
Supply change dissolved component					-19	0	4

North-west marine clay area

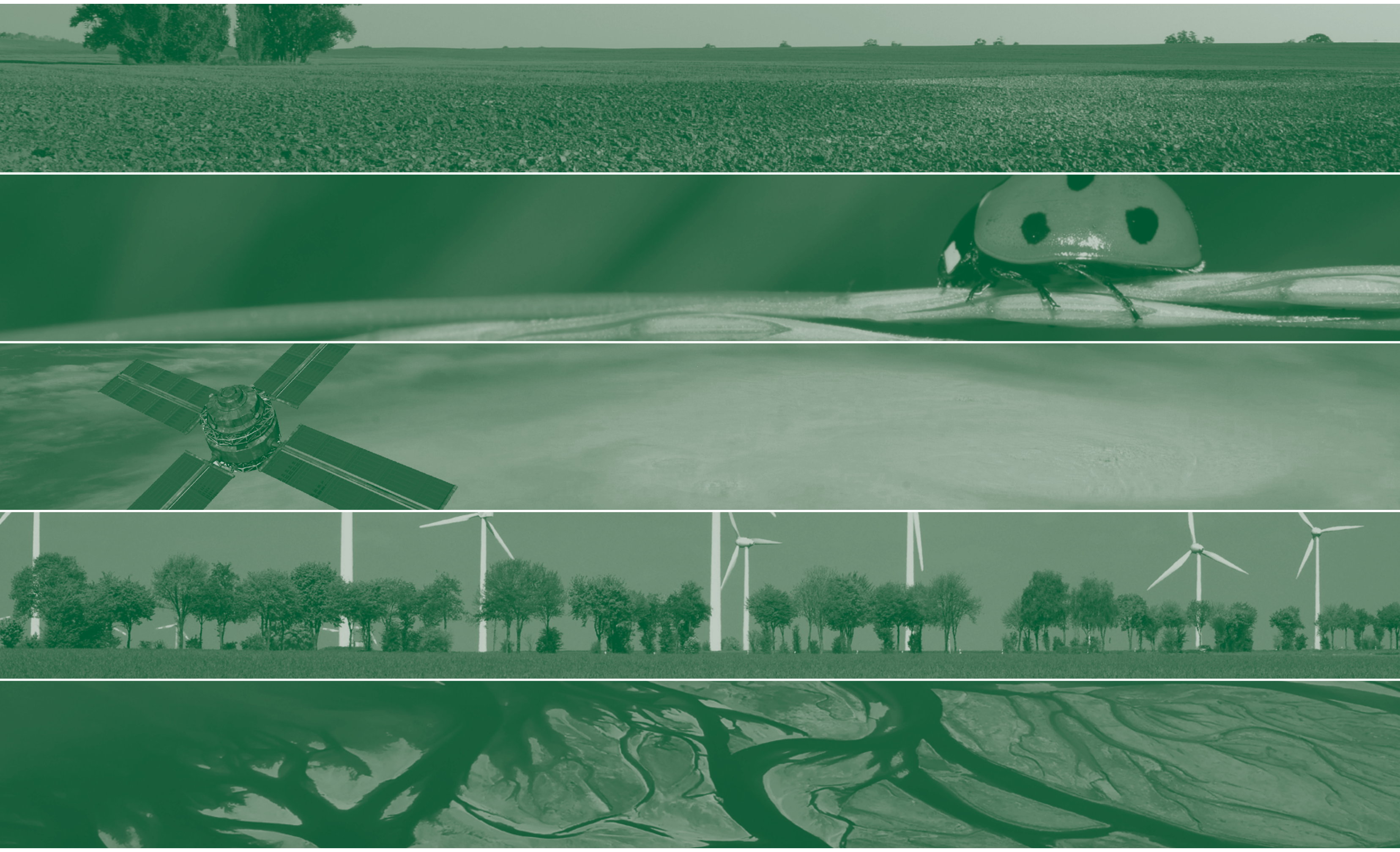
INPUT (kg.ha^{-1} N)	Org-N	NH4-N	NO3-N	OUTPUT (kg.ha^{-1} N)	Org-N	NH4-N	NO3-N
Atm. Deposition		9	8	Crop absorption		156	133
manure and chemical fertilisers	48	132	71	Gross mineralisation	208		
Crop remains	110			Nitrification		160	
Incorporation	33			Denitrification			78
Net mineralisation		175		Ground level run-off	0	0	0
Nitrification			160	Discharge to:			
				- 5th level	0	0	1
Infiltration from:				- drainage pipes	2	9	20
- 3rd level	0	0	0	- 3rd level	0	0	0
- 2nd level	0	0	0	- 2nd level	0	2	1
- 1st level	0	0	0	- 1st level	0	3	1
Upward seepage	1	17	2	Downward seepage	0	0	0
Total INPUT	**193**	**332**	**241**	**Total OUTPUT**	**211**	**332**	**239**
Supply change fixed component / complex					-1	0	
Supply change dissolved component					-18	0	2

Central marine clay area

INPUT (kg.ha^{-1} N)	Org-N	NH4-N	NO3-N	OUTPUT (kg.ha^{-1} N)	Org-N	NH4-N	NO3-N
Atm. deposition		10	8	Crop absorption		98	140
manure and chemical fertilisers	43	123	71	Bruto mineralisation	168		
Crop remains	69			Nitrification		179	
Incorporation	25			Denitrification			98
Net mineralisation		143		Ground level run-off	0	0	0
Nitrification			179	Discharge to:			
				- 5th level	0	0	1
Infiltration from:				- drainage pipes	2	4	23
- 3rd level	0	0	0	- 3rd level	0	1	0
- 2nd level	0	0	0	- 2nd level	0	1	0
- 1st level	0	0	0	- 1st level	0	1	0
Upward seepage	2	9	1	Downward seepage	0	0	1
Total INPUT	**140**	**286**	**258**	**Total OUTPUT**	**172**	**286**	**268**
Supply change fixed component / complex					0	0	
Supply change dissolved component					-32	0	-10

South-west marine clay area

INPUT (kg.ha^{-1} N)	Org-N	NH4-N	NO3-N	OUTPUT (kg.ha^{-1} N)	Org-N	NH4-N	NO3-N
Atm. deposition		10	9	Crop absorption		106	138
manure and chemical fertilisers	47	130	71	Gross mineralisation	176		
Crop remains	68			Nitrification		180	
Incorporation	31			Denitrification			97
Net mineralisation		145		Ground level run-off	0	0	0
Nitrification			180	Discharge to:			
				- 5th level	0	0	1
Infiltration from:				- drainage pipes	1	2	23
- 3rd level	0	0	0	- 3rd level	0	0	0
- 2nd level	0	0	0	- 2nd level	0	1	2
- 1st level	0	0	0	- 1st level	0	2	1
Upward seepage	1	6	1	Downward seepage	0	0	0
Total INPUT	**147**	**291**	**260**	**Total OUTPUT**	**178**	**291**	**266**
Supply change fixed component / complex					0	0	
Supply change dissolved component					-30	0	-6



Alterra is part of the international expertise organisation Wageningen UR (University & Research centre). Our mission is 'To explore the potential of nature to improve the quality of life'. Within Wageningen UR, nine research institutes – both specialised and applied – have joined forces with Wageningen University and Van Hall Larenstein University of Applied Sciences to help answer the most important questions in the domain of healthy food and living environment. With approximately 40 locations (in the Netherlands, Brazil and China), 6,500 members of staff and 10,000 students, Wageningen UR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the exact sciences and the technological and social disciplines are at the heart of the Wageningen Approach.

Alterra is the research institute for our green living environment. We offer a combination of practical and scientific research in a multitude of disciplines related to the green world around us and the sustainable use of our living environment, such as flora and fauna, soil, water, the environment, geo-information and remote sensing, landscape and spatial planning, man and society.

More information:: www.wageningenUR.nl/en/alterra